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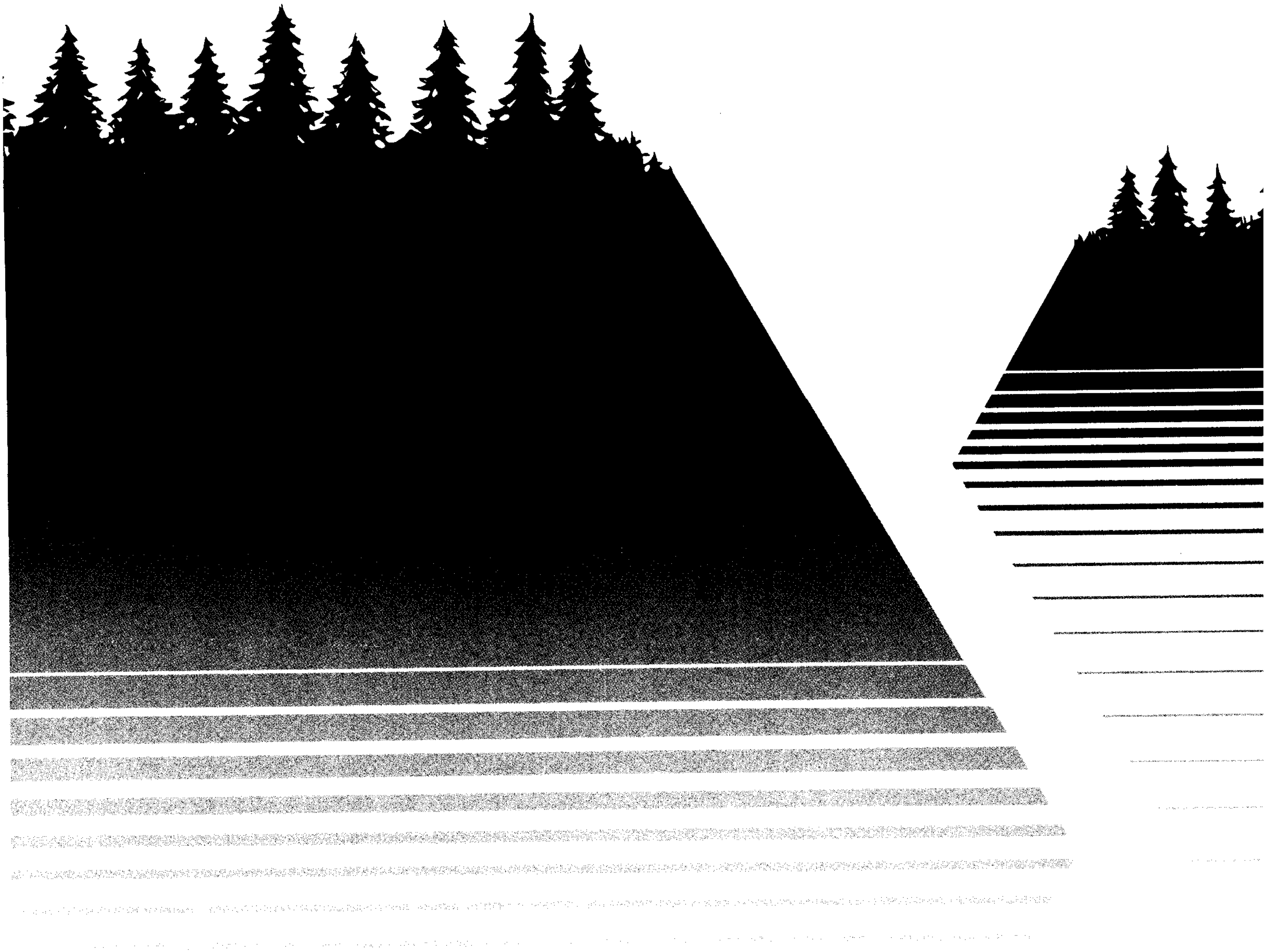
Red Clay Project

Final Part II

Impact of Nonpoint Pollution Control on Western Lake Superior



Preface

The U.S. Environmental Protection Agency was created because of increasing public and governmental concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment.

The Great Lakes National Program Office(GLNPO) of the U.S. EPA was established in Region V, Chicago, to provide specific focus on the water quality concerns of the Great Lakes. The Section 108(a) Demonstration Grant Program of the Clean Water Act(PL 92-500) is specific to the Great Lakes drainage basin and thus is administered by the Great Lakes National Program Office.

Several sediment erosion-control projects within the Great Lakes drainage basin have been funded as a result of Section 108(a). This report describes one such project supported by this office to carry out our responsibility to improve water quality in the Great Lakes.

We hope the information and data contained herein will help planners and managers of pollution control agencies to make better decisions in carrying forward their pollution control responsibilities.

Madonna F. McGrath
Director
Great Lakes National Program Office

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IMPACT OF NONPOINT POLLUTION CONTROL ON WESTERN LAKE SUPERIOR

"Western Lake Superior Basin Erosion-Sediment Control Project"

RED CLAY PROJECT FINAL REPORT PART II

Administration, Public Information, and Education
Research
A Cooperative Interstate Effort Between the
Ashland, Bayfield, Carlton, Douglas, and Iron County
Soil and Water Conservation Districts

Prepared by:

STEPHEN C. ANDREWS
Project Director

RALPH G. CHRISTENSEN
Section 108(a) Program Coordinator

CARL D. WILSON
Project Officer

Prepared for:

U.S. ENVIRONMENTAL PROTECTION AGENCY
Great Lakes National Program Office
536 South Clark Street, Room 932
Chicago, Illinois 60605
(312) 353-2117

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COOPERATING AGENCIES AND PERSONNEL

Arrowhead Regional Development Commission
 Richard Isle

Minnesota Department of Natural Resources
 Dan Retka

Minnesota Pollution Control Agency
 John Pegors

Minnesota Soil and Water Conservation Board
 Steve Pedersen
 Vern Reinert

National Association of Conservation Districts
 William Horvath

Northland College
 Robert Brander
 Tom Klein
 Virginia Prentice

Northwest Regional Planning Commission
 Mark Mueller
 John Post

United States Army Corps of Engineers
 Louis Kowalski

United States Bureau of Indian Affairs -,USDI
 Charles McCudy

United States Environmental Protection Agency
 Ralph Christensen
 Carl Wilson

United States Geological Survey
 Eno Giacomini
 Steve Hindall
 Vito Latkovich
 William Rose
 Ron Wolf

United States Soil Conservation Service - USDA

Clarence Austin
Don Benrud
John Ourada
Steve Payne
John Streich
Peg Whiteside

University of Minnesota-Duluth

Don Olson
Michael Sydor

University of Minnesota-Extension

Arnie Heikkila

University of Wisconsin-Extension

William Lontz
Raymond Polzin

University of Wisconsin-Madison

Tuncer Edil
Peter Monkmeyer

University of Wisconsin-Milwaukee

Bruce Brown

University of Wisconsin-Stevens Point

Bob Burull

University of Wisconsin-Superior

David Bray
Donald Davidson
Philip DeVore
Albert Dickas
Larry Kapustka
Rudy Koch
Joseph Mengel
William Swenson
Paul Webster

Wisconsin Board of Soil and Water Conservation Districts

Don Houtman

Eugene Savage

Wisconsin Department of Natural Resources

John Konrad

Wisconsin Department of Transportation

Emil Meitzner

Wisconsin Red Clay Interagency Committee

William Briggs

Garit Tenpas

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INTRODUCTION

The Final Report of the Red Clay Project is presented in three parts: Part One, published in November 1978, presents a summary of results, conclusions and recommendations for the Project; Part Two consists of the texts of the Final Reports prepared in the areas of general administration, public information and education, and research; Part Three consists of the texts of the Final Reports prepared in the fields of installation, applications research and monitoring.

In the case of Parts Two and Three, the technical appendices accompanies the appropriate text.

The Table of Contents for Parts Two and Three are both found in their entirety in each document for cross-referencing purposes. It should be noted, that some reports do not have a corresponding appendix. In the case of Erosion Survey Phases I & II, prepared by Bray, Dickas and Webster, the appendix is so large as to prohibit publication. Similarly, the water quality data generated by the U.S. Geological Survey is referenced by STORET reference number and are not presented in toto.

Specific requests for information should be forwarded to the Principal Investigator responsible for the project.

PROJECT SUMMARY

by

Stephen C. Andrews
Project Director

Since the first settlers arrived in the western Lake Superior basin, the red clay soils dominating the region have presented problems. For those involved with lumbering, construction, agriculture and transportation, the primary concern was the pervasiveness of the erosion problem and associated damages and costs.

With the formation of soil and water conservation districts in the 1930's and 1940's, the red clay erosion problem, particularly as it affected agriculture, began receiving attention. In the early 1950's the first systematic study of erosion and land use problems was initiated in Wisconsin by the governor-appointed Red Clay Interagency Committee. This early work was primarily aimed at demonstrating techniques for reducing upland and roadside erosion and stabilizing streambanks. The focus of this committee's efforts was more on treating the erosion problem than on abating water pollution.

The first Lake Superior Water Quality Conference in the early 1970's focused some attention on the south shore erosion and sediment problems. In response, Wisconsin's Red Clay Interagency Committee was given the charge of identifying the extent of the problem and outlining an erosion and sediment abatement plan.

At about this same time, the soil and water conservation districts from Douglas County, Wisconsin and Carlton County, Minnesota met jointly to consider ways of reducing erosion in the Nemadji River Basin. With assistance from the Northwest Wisconsin Regional Planning Commission, the Onanegozie Resource Conservation and Development Project and the Pri-Ru-Ta Resource

Conservation and Development Project, the two districts prepared plans for studying the problems and originated proposals for funds to implement the plans.

In 1973 the Wisconsin Board of Soil and Water Conservation Districts was instrumental in arranging a tour of the red clay area for representatives from Region V of the United States Environmental Protection Agency. The Environmental Protection Agency was authorized by Congress to demonstrate new methods for improving water quality in the Great Lakes with funding provided by Section 108 of the 1972 Amendments to the Federal Water Pollution Control Act. In May of 1974 with a grant from the U.S. Environmental Protection Agency and the continuing assistance of many agencies, the soil and water conservation districts from Ashland, Bayfield, Douglas and Iron Counties in Wisconsin and Carlton County in Minnesota began the Red Clay Project.

This document is the final report of the Red Clay Project. It is the summary report which presents the project's findings, conclusions and recommendations and is accompanied by a technical report which contains detailed accounts on the various research and demonstration activities.

NONPOINT SOURCE POLLUTION PROBLEMS

With the passage of the 1972 Amendments to the Federal Water Pollution Control Act (Public Law 92-500), a renewed national emphasis was placed on solving the problems of water pollution. This act granted powers and authorities for studying the problems and for planning workable ways to solve them.

The act classified the serious water quality problems which inspired it into two major types based on their source. "Point" sources of pollution include readily identifiable sources such as municipal sewage treatment plants and industrial waste discharge systems. "Nonpoint" sources of pollution are less easily identified because they are varied and diffuse.

They include runoff and seepage from agricultural land, urban areas, forestry activities, construction and maintenance operations, and mining sites.

Common pollutants from nonpoint sources are sediment, nutrients, pesticides, heavy metals and salts. Of these, sediment is the most abundant and, in some ways, is the most severe because it is not only a pollutant itself, but transports other pollutants.

RED CLAY PROBLEMS

The red clay area of the western Lake Superior basin extends in a narrow band from northeastern Minnesota to the western portion of Michigan's upper peninsula. The predominant soils in this area are red clays interspersed with sands and silts. They were originally deposited as lake sediment during glacial periods but now, due to lake recession and geologic uplift, they form much of the land mass of present-day Lake Superior's south shore.

The soils are young and are undergoing a high rate of natural erosion as a geologic equilibrium evolves. When man settled in the area his lumbering, construction and agricultural activities removed the established vegetation and altered drainage patterns in ways that accelerated this already high rate of erosion. Present-day activities, although not intensive, do still aggravate the erosion processes. In turn, erosion is detrimental to man's land and water-based activities alike.

The major nonpoint sources of pollution in this area are the lakeshores, streambanks and other slopes. The damaging pollutants are sediment, turbidity and color. The heterogeneous mixture of clay and sand produces soils with very little stability which, when exposed to varying moisture conditions on steep slopes, often erodes severely. Once in the water, the heavy particles settle out as sediment and the fine particles remain suspended for long periods increasing the water's turbidity. Further, the red clays contain approximately 2 percent extractable iron oxide which produces a very visible and objectionable color. It is this iron oxide which is responsible for the red color of the streams and the red plumes where streams discharge into Lake Superior. This phenomenon occurs even when the turbidity and sediment rates are low.

THE RED CLAY PROJECT

The Red Clay Project was a research and demonstration project sponsored by five soil and water conservation districts from two states. The local district supervisors were committed to the task of seeking practical solutions to the many forms of red clay erosion and the resulting water quality problems. To assist them in their task, they applied for and received a grant from the United States Environmental Protection Agency under the provisions set forth in Section 108 of the 1972 Amendments to the Federal Water Pollution Control Act (PL 92-500). The overall objectives of this partnership were to demonstrate economically feasible methods of improving water quality, to assess the capabilities of existing institutions to cooperatively implement a pollution control program and to provide data and recommendations that could be used in future programs.

The agreement between the federal Environmental Protection Agency and the local soil and water conservation districts involved considerably more interagency cooperation than a strictly two-way, federal-local alliance. Soil and water conservation districts have been legally empowered by their respective states to enter into cooperative agreements with other units of government and their agencies to accomplish common objectives. Since their inception, districts have built up working relationships with numerous federal, state and local agencies. Using their legal authorities and these established relationships, the soil and water conservation districts from Ashland, Bayfield, Douglas and Iron Counties in Wisconsin and Carlton County in Minnesota joined together and called upon their cooperating agencies to help them develop, implement and evaluate the Red Clay Project.

To govern this complex association of institutions, the sponsoring districts formed an executive committee with equal representation from each district. The Douglas County Soil and Water Conservation District was designated the fiscal agent and it assumed responsibility for the grant with the Environmental Protection Agency. The chairman of this five-member committee was also from the Douglas County District. The function of the executive committee was to set administrative policy, approve programs and administer financial affairs.

Although the Douglas County Soil and Water Conservation District was appointed the fiscal agent, under the terms of the grant agreement the individual districts maintained the authority to manage programs within their district. This authority held by the individual districts included the power to write contracts, make local financial decisions and operate and maintain their own programs and installations. This procedure allowed districts to manage the project in their area consistent with their ongoing programs and policies.

In a similar manner, each soil and water conservation district retained the power to conduct other Red Clay Project operations in a manner consistent with the established order in that district. A voluntary compliance approach was used to solicit participation by local units of government and private landowners. Participation, therefore, depended upon individual priorities, budgets and the ability to provide local services and to meet local costs. The solicitation of landowners for participation in the Red Clay Project was done by each conservation district following procedures established by that district. The cost-share rates were consistent with local conservation aid programs and were not specifically designed to encourage program participation with artificially high rates.

Although many of the project operations were controlled by the individual soil and water conservation districts, overall procedural uniformity was maintained through the use of an operations manual. This manual, prepared especially for the project, outlined procedures for reviewing and approving program items and for obtaining reimbursements in a timely fashion.

AREAS OF STUDY

Early in the development of the project, several directions for field study were identified by the executive committee and the project director with the assistance of a multiple-agency technical and research advisory committee. Research and field demonstration projects were chosen which would increase the understanding of the mechanisms affecting the pollutant load to area streams and to Lake Superior. Areas of study were also selected which would, in turn, identify the effects of this pollutant load on the streams and the lake. An attempt was made to incorporate a wide range of problem areas but at the same time to have them complement one another and provide an integrated picture of the erosion and water quality problems of the red clay area. A premium was placed on the generation of data essential to the formulation of useful recommendations for the development of long-term water quality programs.

Geographical study areas which were selected were representative of conditions in the entire watershed. Research was conducted only in the Nemadji River basin. The monitoring of water quality and climatic conditions was carried out in all geographic areas where research and field demonstration activities were performed. The following criteria were used to select geographical areas for project studies:

1. The proportion of loamy glacial till and sandy beach deposits in the uplands with respect to the clayey lacustrine basin.
2. The relationship of present land use patterns within the study area to land use patterns in the basin. The ratio of open cropland and pasture to woodland was used to indicate the relative intensity of land use within the area.
3. The presence of actively eroding areas along the river channels and drainageways. Erosion conditions in the geographical areas were representative of those in the entire basin.

4. The roadside erosion taking place within the study areas. Roadside erosion in the study areas was also representative of the entire basin.

5. The land ownership patterns. Land rights were generally easier to obtain and it was assumed that ongoing practice maintenance would be easier on publicly owned land.

6. Access to the work sites. Most of the eroding areas in the basin had very limited access. Although it was necessary to construct some roads, this was minimized by attempts to select easily accessable sites.

7. The distribution of geographical study areas to coincide with political boundaries. An attempt was made to have at least one study area in each soil and water conservation district. The work done in each study area was determined by the needs of the sponsoring district, the budget limitations of that district and the project and the uniqueness of the site and the proposed work.

Using these considerations, six geographical study areas were selected. In the following discussion, references made to the sediment-producing capabilities of these watersheds were based on the use of the Universal Soil Loss Equation during the planning stages of the project. The study areas delineated for the Red Clay Project were:

1. Skunk Creek Watershed in Carlton County, Minnesota -- A relatively high sediment-producing basin covering approximately 10.7 square miles. Land use intensity within the basin was relatively low. There were, however, numerous streambank and roadside erosion sites in this subwatershed.

2. Little Balsam Creek Watershed in Douglas County, Wisconsin -- A moderate sediment-producing watershed covering about 5.4 square miles. Land use intensity within the basin was judged to be relatively low.

3. Pine Creek Watershed in Bayfield County, Wisconsin -- A moderate sediment-producing basin covering approximately 15.7 square miles. Land use intensity here was estimated to be moderate.

4. Spoon Creek Watershed in Iron County, Wisconsin -- A moderate sediment-producing watershed covering about three square miles. Land use intensity was low.

5. Madigan Beach in Ashland County, Wisconsin -- As a site for shoreline protection work, Madigan Beach was selected for its high, actively eroding bluffs and exposure to severe, Lake Superior storms.

6. Indian Cemetery Beach on Madeline Island in Ashland County, Wisconsin -- As another area for shoreline protection demonstrations, this site was selected for its low bluff, narrow beach and cultural and historical significance.

RED CLAY SLOPE STABILITY STUDIES

Red Clay Project researchers undertook studies of the condition and behavior of the soils within the Lake Superior red clay area. The purpose of the studies was to utilize available sampling and testing techniques and opportunities to determine the depths of the zones in which massive slope failure normally occurs. Also studied were the mechanical properties and behavioral traits of the soils and their relationships to slope stability and rates of erosion.

These studies resulted in findings which have broadened the field of information on which our understanding of the soils of this region is based. Several conclusions were arrived at from which corrective measures can be derived. The findings and conclusions are:

1. The clay soils of this region generally contain approximately two percent extractable iron oxide.

2. Man's early removal of the forest cover, modification of natural drainage patterns and other activities have promoted

drying in a five to seven foot thick surface zone of the clay soils.

3. Drying in this surface zone has changed the mechanical behavior of the clay from a plastic solid to a brittle solid susceptible to fissuring and massive slope failure.

4. Moisture accumulation in fissures provides the necessary lubrication for flowing and sliding to occur within the surface zone.

5. The topography of the red clay area will continue to evolve under the influence of natural processes.

6. There are workable practices which man can incorporate into land use plans which will slow natural erosion processes.

THE SIGNIFICANCE OF VEGETATION IN MODERATING RED CLAY EROSION

The Red Clay Project conducted research on the relationship between erosion and vegetation. Two studies were done to determine how vegetation helps control the amount of water in the soil. Soil stability was suspected to be related to a rather narrow range of moisture content. Dry conditions encouraged soil fractures and crumbling, while wet conditions created liquid-like conditions and soil slippages. Another study was undertaken to determine the way plant roots exert holding power to counteract soil movement.

The findings and conclusions of these studies are:

1. Vegetation plays a major role in retarding erosion in the geologically young red clay soils. However, no type of vegetation alone can completely offset the natural erosion forces.

2. Grasses and herbaceous plants yield beneficial anti-erosion effects. However, their relatively shallow and weak roots do not serve to prevent massive slope failure in surface zones where brittle clay conditions already exist.

3. Woody plant species have stronger root systems which do help prevent slides.

4. Of all vegetation types, climax woody species (such as firs, pines and maples) provide the best erosion control because of their stronger root systems and the manner in which their canopies intercept rainfall.

5. Woody climax vegetation species are not efficient at lowering soil moisture content.

6. Herbaceous species and some woody species (aspens) are relatively more efficient at removing water from soil.

7. The use of vegetative methods specifically for reducing soil moisture content in the surface zones of red clay soils has not been shown to be beneficial for controlling massive slides. Species which are best suited for water removal (grasses and aspens) are most effective in drier years when they tend to lower moisture content too far which, in turn, induces fracturing, fissure formation and a greater potential for massive slide erosion.

THE EFFECTS OF RED CLAY TURBIDITY AND SEDIMENTATION ON AQUATIC LIFE IN WESTERN LAKE SUPERIOR BASIN RIVERS

Research was undertaken to assess the effect of relatively low levels of sedimentation and turbidity on aquatic life in red clay area streams. Through systematic water quality monitoring, sampling aquatic life populations and assessing the aquatic environment, researchers studied behavioral patterns of numerous species of aquatic life in both natural and laboratory settings. Researchers were looking for relationships between these aquatic animal species and varying levels of nutrients, turbidity and sedimentation.

Previous aquatic life studies in other areas had focused on situations where man's activities such as logging, mining and agriculture had had the effect of creating extremely high levels of stream sedimentation. The glacial lake deposits of the

Nemadji River system are highly erodible even under strictly natural conditions. However, due to the nature of the interrelationship between red clay erosion and red clay sediment, the small particle size of the clay and the amount of extractable iron oxide in the clay, the general condition of the streams is one of low sediment loads, low turbidity and a high amount of color.

Aquatic problems attributed in the past to red clay turbidity have included the substitution of undesirable fish species for more desirable ones, negative effects on spawning runs, decreased oxygen levels and increased nutrients as well as general observations on "adverse effects on biological life processes." None of these statements can be supported by the findings from this research in the Nemadji River basin.

Analysis of areas of Lake Superior and the Nemadji River system which are turbid throughout the year due to erosion of unconsolidated glacial lake deposits indicated that any direct, physical effects of this turbidity and resultant low level sedimentation are minimal. Furthermore, although turbidity does induce important changes in aquatic life behavioral patterns, changes found through this research were, for the most part, considered beneficial rather than detrimental to the survival of native species.

Although a positive balance seems to have been struck between present levels of turbidity and sedimentation, and existing aquatic life in the red clay portions of the Nemadji River, the potentially severe effects of erosion on aquatic life elsewhere, or even here under artificially accelerated conditions, should not be underestimated. It is well known that soil mismanagement can upset the natural balance to the extent that severe short and long-term consequences are inevitable for aquatic flora and fauna.

The findings of this research are that:

1. Red Clay does not contribute significant quantities of nutrients to Lake Superior but may serve to transport nutrients contributed from other sources.

2. Oxygen levels are not significantly affected by red clay or associated organics.

3. Primary production does not appear to be significantly affected by turbidity within the range of depths at which most production occurs in these relatively shallow streams.

4. Bacteria exhibit no definite trends with turbidity within sites, but do seem to have higher counts in turbid than in non-turbid sites. Fungal counts exhibit opposite trends. Bacterial and fungal populations are generally beneficial to the aquatic system as they are the primary food source for many of the macroinvertebrates.

5. Number of macroinvertebrates per unit area, total number of taxa, diversity, and biomass are not significantly affected by clay turbidity and siltation within the Nemadji River system.

6. The size of particles on the stream bed had much greater effects on macroinvertebrates than turbidity and sedimentation. Only where sand was the primary product were significant detrimental effects of erosion identified.

7. All genera of insects which occurred in clear streams also occurred in turbid streams. Certain insects generally associated with silts, especially certain mayflies and beetle larvae, were found only in the turbid streams.

8. Laboratory monitoring of activity and respiration of the stonefly demonstrated no significant effects at turbidity levels normally encountered in the Nemadji River basin.

9. Fish populations were not demonstrated to change as a result of turbid conditions but rather, because of water temperature and discharge differences between turbid and clear water sites. All species benefitted from increased cover which is harder to maintain in turbid streams due to increased tendencies for slippage at toes of the clay banks.

10. Walleye in the lower Nemadji River, the Duluth-Superior harbor, and Lake Superior benefit from red clay turbidity as it enables them to inhabit the shallow, more productive waters.

11. Rainbow smelt and four species of suckers successfully reproduce in the turbid areas of the Nemadji River.

12. Egg survival bioassays with walleye and rainbow smelt indicated decreased survival at turbidities over 10 ftu. Survival was at least half of control at turbidities prevalent in the Nemadji River. Levels of sedimentation in the bioassay were much higher than in the natural system, probably resulting in higher egg mortality than would naturally occur.

13. Channel form and available cover are the primary factors affecting fish population size for all species in the Nemadji River system.

LAND MANAGEMENT PRACTICES

Although the Red Clay Project offered innovative opportunities and unique challenges, most of the "on-land" erosion control measures were not entirely new to local officials, farmers and other managers of the land. All the counties had long been designated soil and water conservation districts and had applied conventional soil conservation programs frequently in cooperation with the Soil Conservation Service and other institutions.

What was new was the opportunity to accelerate these programs in areas of each district where red clays pose widespread and persistently critical erosion problems. What was unique was the challenge of adapting conventional soil management techniques to the perplexing red clay conditions. What was innovative was a mandate to apply these traditional measures in combinations and in locations which would yield some demonstrable impact on water quality.

A typical five-step, problem-solving approach was followed by investigators in assisting with land management practices.

Generally, the first step was to identify critical problems and inventory their locations. The second step was to develop alternative solutions. The third step was to assist in the selection of the most feasible and acceptable solutions. And the fourth and fifth steps were to implement and evaluate the selected land management practices. The presence of an overriding objective of enhancing water quality, and not simply of preventing soil loss, served to influence the work, and decisions about it, throughout each of the five problem solving steps. Thus, to cite a hypothetical example, given a choice between treating a severely critical fertile area which had little likelihood of loading its eroding soil into a water course or treating a moderately critical fallow-soil area which was certain to degrade a nearby body of water, the latter would receive attention through the Red Clay Project.

The Universal Soil Loss Equation was used as an indication of soil loss and the effectiveness of land treatment. The equation could not address the problem of transport nor could it be applied to raw streambanks or slide areas adjacent to streams. In Pine Creek, 90% of the land area averaged .15 tons per acre per year soil loss. Little Balsam Creek study area averaged .55 tons per acre per year and Skunk Creek was within the allowable soil loss (3-5 tons per acre per year). The average annual estimated soil loss for the study areas was slightly less than 1.0 ton per acre. These soil loss estimates indicate that a relatively small percentage of the total land area contributes a disproportionately large share of the sediment in streams and lakes. The task of matching conservation practices to such critical areas is a process which must include an awareness to conditions specific to each site as well as a sensitivity to landowner attitudes, project costs and potential benefits.

Although any erosion control practice may be appropriate under certain conditions, those practices which have been found to be the most applicable to conditions encountered during the course of the Red Clay Project are listed below. The selection of these practices as the most applicable is based on evaluations using the Universal Soil Loss Equation and on-site inspections.

1. Maintenance of Vegetative Cover. This practice includes managing for trees, grasses, crop residue and other materials which maintain surface cover and protect the soil from erosion.

2. Livestock Exclusion. This practice removes or restricts livestock entry into critical areas. Complementary practices are necessary to maintain this practice.

3. Alternate Watering Facilities. This is a complementing practice for livestock exclusion. Watering facilities allow for proper distribution of livestock and provide an alternative to instream watering.

4. Stock Trails and Walkways. This is a complementing practice for livestock exclusion. Livestock trails and walkways provide access to areas without creating additional erosion.

5. Livestock Stream Crossing. This is a complementing practice for livestock exclusion. Livestock are kept out of streams and provided access to pasture and watering areas. Streambanks and other critical areas are also protected.

6. Critical Area Seeding. This includes the establishment of permanent vegetative cover on critical areas.

7. Grassed Waterways and Diversions. This practice involves the safe disposal of runoff in properly installed and maintained grass channels. It reduces soil erosion and provides stable outlets for runoff.

8. Animal Waste Management Systems. This practice includes the control of running water through areas of heavy use by livestock and the development of a system of storage, disposal and utilization for animal wastes to reduce water pollution. Components of an animal waste system

are waste storage facilities, water disposal and erosion protection devices (diversions and waterways), animal waste disposal plants, and cropping systems.

9. Sediment Traps. These practices are basins created by water retention structures to trap and store sediment.

10. Streambank Protection and Slide Stabilization. This includes any protection and stabilization practices which withhold significant amounts of sediment from adjacent waters.

11. Floodwater Retarding Structures. These structures serve the primary purpose of temporarily storing floodwater and controlling its release.

THE EVALUATION OF WORKS PREVIOUSLY INSTALLED BY THE WISCONSIN RED CLAY INTERAGENCY COMMITTEE

From 1958 through 1967, erosion control practices were installed in Ashland, Bayfield and Douglas Counties by the Wisconsin Red Clay Interagency Committee. These practices were monitored and evaluated by that committee and their findings were previously reported. Members of the committee were asked by the Red Clay Project to reevaluate their work to determine the effectiveness of the erosion control methods and practices after adequate time had elapsed for them to have responded to a wide range of weather conditions. The reevaluation also provided current data on erosion control practices and procedures which could be compared with practices and procedures used by the Red Clay Project.

The work done by the Red Clay Interagency Committee primarily consisted of roadside and streambank erosion control measures. Some upland treatments such as grassed waterways were also installed. The reevaluation concluded that, after a lapse of ten to twenty years:

1. Generally, most of these accepted erosion control practices withstood the weathering effects of the past

one to two decades and helped stabilize the areas where they were installed.

2. When treating bank erosion, stabilizing the toe of the bank is of primary importance.

3. Proper slope modification, seedbed, preparation and seeding mixtures are necessary to establish protective and stabilizing vegetation.

STREAMBANK AND ROADSIDE EROSION SURVEY

The Red Clay Project undertook a program to collect all existing data on the extent of roadside and streambank erosion problems and to inventory as many of the unsurveyed areas as possible within time and monetary limits.

During the first phase of this program, the literature-search, the most recent survey data on streambank and roadside erosion in the red clay area was collected from all available sources. This information was recorded on maps and in tabular form. The second phase was to survey erosion sites along those roadsides for which data was not obtained in the literature-search and, thereby, making complete the erosion survey of all roadsides in the red clay area of the five counties. Portions of three rivers whose watersheds contrast agricultural land use, recreational use, and undeveloped or wild area were also inventoried. The purpose of the streambank survey was to compare erosion patterns in an attempt to determine the impact of land use.

The information collected from this study was used as support data for other project activities and will be available for future use by researchers, soil and water conservation districts and others applying conservation practices. The findings of the comparative streambank survey are:

1. Despite differences in land use, the major cause of erosion along all three streams was basically natural. Direct erosion by differential stream discharge undercutting and the resulting bank failure constituted nearly all of the observed erosion sites.

2. At only a few sites was erosion observed that could be directly related to agricultural use and here the direct cause was that of migrating livestock.

3. Man-caused erosion on the banks of the recreational-use stream was evidenced at canoe entry and exit sites. The damage caused by recreational and agricultural use was categorized as minor.

SHORELINE DEMONSTRATION, MONITORING AND EVALUATION

Protective, preventive and remedial erosion control measures employable under conditions typical of those encountered along the western Lake Superior shoreline were demonstrated by Red Clay Project researchers at two sites in Ashland County. Interest evidenced in this aspect of Red Clay Project work was, to some extent, attributable to the severity of the problems and the uniqueness of the areas involved. Interest also centered around a contrast in techniques, one conventional and the other innovative.

One of the sites, Madigan Beach, was selected for its high, actively eroding bluffs and its exposure to severe storms. Here a technology entirely innovative for Lake Superior, the installation of Longard tubes, was employed. Longard tubes are large, flexible vinyl tubes filled with sand and coated with a protective epoxy paint. They were placed in a variety of patterns designed to protect the base of shoreline bluffs and to build up a protective sand beach. Design layouts used by Red Clay Project researchers included differentially-spaced groins, seawalls and groin-seawall combinations.

The second site, the Indian Cemetery on Madeline Island, was chosen because of its low bluff, narrow beach and historical and cultural significance. Here a conventional rubble-mound revetment was installed.

Both shoreline protection projects underwent construction during the summer of 1977. Subsequently they were monitored and evaluated by Project investigators. At the end of the Red Clay Project, arrangements were made for the U.S. Army Corps of Engineers to initiate a continuous monitoring process for the work at these two locations.

Findings and conclusions which can be offered on the basis of monitoring and evaluation activities completed to date are:

1. Longard tubes appear to be competitive in both cost and performance with more conventional shore protection and beach stabilization structures.
2. Bluff modifications may be an important factor in the successful performance of Longard tubes.
3. Rubble-mound revetments provide positive shore protection at sites with conditions similar to those found at the Indian Cemetery site.

WATER QUALITY MONITORING

Monitoring of water quality and sediment was conducted at thirteen project stations. The samples were analyzed for over fifty physical, chemical and biological parameters. In addition, a ground water study was undertaken in Calrton County, Minnesota and a bedload transport study was conducted in the Nemadji River in Douglas County, Wisconsin.

The findings of these activities are:

1. The streams of the red clay area are predominantly event-response in character.
2. Pesticides and herbicides were not found at any concentration in either the water or bottom material samples.
3. Heavy metals were not found except for trace concentrations at detection levels.
4. Fecal coliform -- fecal streptococci ratios indicate livestock and wild animals as the primary contributors of fecal waste. Game management and farm animal estimates indicate that 50% or more of the fecal waste is generated

by non-farm animals (population density of 18 persons/mi^2, 15 deer/mi^2, 10 farm animals/mi^2). Shifts in contribution did not occur with fluctuation in flow.

5. Nemadji River suspended sediment concentrations range from 2 mg/L to 1190 mg/L with a 3 year daily mean of 77 mg/L.
6. Nemadji River total phosphorus concentrations range from .01 mg/L to .36 mg/L with a 3 year mean of .08 mg/L.
7. Nemadji River total nitrogen concentrations range from .10 mg/L to 2.4 mg/L with a 3 year mean of .63 mg/L.
8. Nemadji River organic nitrogen concentrations range from .1 mg/L to 2.2 mg/L with a 3 year mean of .48 mg/L. Organic nitrogen is approximately 76% of the total nitrogen and is consistent with expectations of forested watersheds.
9. Except at stations immediately downstream from construction activities it was impossible to identify construction related changes in suspended-sediment concentrations.
10. In a very small watershed such as Pine Creek it was possible to identify upward suspended-sediment concentration shifts that were not related to changes in flow and were probably the result of bank collapse or in-stream activities.
11. The Minnesota ground water study found that in the deep valleys of the upper Nemadji River there is a tendency for upward movement of ground water. This upward movement may cause wetting of fissure zones from beneath thus triggering slides.
12. The Nemadji River bed load transport study found that only 3% of the total sediment load is transported on the bed of the river.

WESTERN LAKE SUPERIOR BASIN RAINFALL AND TEMPERATURE MONITORING

The Red Clay Project conducted a monitoring program designed to record on a continuous basis the intensity of rainfall and wind and to profile the temperature of the air and soil. The program used existing monitoring technology wherever possible, but also involved the development of new low-cost instrumentation techniques. It took place at locations throughout the Skunk, Little Balsam and Pine Creek watersheds.

This micrometeorological data base was generated for its usefulness in illuminating otherwise latent cause and effect relationships between soil loss due to erosion and natural phenomena such as the presence and intensity of rainfall and significant fluctuations of soil temperature along steep banks. The information gathered represented a support service to other research activities and, as such, provided no independent conclusions. However, the results are reflected in related research work.

One of the major developments of this program was the production and refinement of a low-cost system for continuously monitoring precipitation, wind, air and soil parameters at remote sites.

INSTITUTIONAL COOPERATION

The first organized efforts to systematically study red clay erosion and sedimentation problems were distinguished by a unique and extraordinary amount of interagency cooperation. In Wisconsin, the Red Clay Interagency Committee was composed of several state and federal agencies based in the state capital. When working in the red clay area, they received cooperative assistance from locally-based representatives of many more local, state and federal agencies. The Carlton County Soil and Water Conservation District in Minnesota joined with the Douglas County District in Wisconsin to form an interstate alliance of conservation districts to seek approaches and funding sources for solving their shared problems.

This multiple agency approach was continued by the Red Clay Project. Rather than attempting an elaborate analysis of what institutional systems might work best, it was determined to use existing relationships developed over the years by county soil and water conservation districts. Throughout the United States, enabling legislation had been passed in each state that permitted the creation of conservation districts as special purpose units of state government. Although they developed differently over the past forty years, districts generally evolved into political entities having effective working relationships with nearly every local, state and federal unit of government and agency concerned with natural resource conservation.

Soil and water conservation districts in Minnesota and Wisconsin are functionally alike in terms of objectives, authorities and district operations. In both states, districts have similar legal responsibilities to conserve the natural resources within their boundaries. They also have similar legal authorities to enter into agreements with other units of government to accomplish common goals. The major difference between them is that in Wisconsin, district supervisors are elected members of the county board who serve on the agriculture committee while in Minnesota, supervisors are elected at large.

Because of the wide geographical area covered by this basin-wide research and demonstration project and because of its five-district, two-state sponsorship, a multiple agency approach to project operations was selected. The sponsoring soil and water conservation districts formed a project-governing executive committee consisting of equal representation from each of the districts. The Douglas County Soil and Water Conservation District was designated the fiscal agent for the entire project and its representative to the committee served as chairman. The committee met monthly to conduct project business. Through agreements, the scope of work and procedures for each district were identified.

Representatives from participating agencies were called together to form a technical advisory committee, an information-education advisory committee and a program advisory committee. These committees met in special sessions and, upon request at the monthly meetings to advise the executive committee regarding project operations. Because none of the districts had staff trained in managerial capabilities, project staff were hired through contracts with capable agencies. All project work elements were accomplished by cooperating agencies and institutions working under contract for the project.

As was stated earlier, the intent of the Red Clay Project was for the existing institutions, soil and water conservation districts, to run the project. No systematic attempts were made to analyze or evaluate these relationships. The following findings and observations are based on subjective assessments by the project director, project specialist and other investigators closely involved with the management and operations of the project.

1. Five soil and water conservation districts from two states effectively sponsored and managed a basin-wide research and demonstration project.

2. The multiple agency approach followed by the project proved to be highly successful even though differences in standards, funding mechanisms and implementing procedures between states posed many communication and operation difficulties.

3. The application of conservation practices was influenced by landowner attitudes, long-range costs and site-specific conditions as well as potential benefits, immediate costs and the general applicability of considered "best" management practices.

4. The application of conservation practices relied upon the voluntary compliance of landowners and units of government. Attempts to prepared and implement a sediment control ordinance met with considerable resistance from local elected officials.

5. In certain critical areas, zoning ordinances or regulations may be the most effective tool to achieve erosion control.

6. Due primarily to a lack of adequate funds, there was a noticeable inability on the part of some town-level and city departments of government to cooperate with soil and water conservation districts.

7. None of the sponsoring soil and water conservation districts had staff capable of managing district affairs and projects.

8. Soil and water conservation districts had to rely principally upon federal and state funds to carry out a program of the magnitude and intensity of the Red Clay Project.

9. Higher cost share rates did help induce landowner cooperation, however many other factors (e.g. landowner attitudes, practice maintenance, landowner age, specific farm conditions, encouragement from neighbors and professionals) were influential in determining which practices were applied.

RECOMMENDATIONS

Soil and Water Conservation Districts should be designated as the local management agency.

The local management agency should be given early and continuous involvement in establishing and managing any future non-point source pollution control programs, plans and strategies affecting its area.

The local management agency should be adequately staffed, and constituted so as to provide balanced representation of the area and its water quality interests.

In rural areas where regional problems have been identified, multijurisdictional cooperation should be used as an effective approach for management programs.

Because of significant differences in standards, funding mechanisms and implementing procedures, non-point source pollution control programs in rural area should not involve more than one state.

Multi-agency programs should have a common focus through a single set of goals, objectives and policies to insure effective management and uniform results.

Sufficient evaluation should be conducted prior to implementation to clearly identify critical areas and influential parameters, thus ensuring cost-effective abatement.

Sufficient, but not excessive, levels of cost-sharing should be provided as an incentive for cooperation and to help defray landowner costs.

The local management agency should provide educational programs for citizens, cooperating units of government and agencies to establish and maintain an awareness of water pollution problems and abatement strategies.

The local management agency and its staff should establish close working relationships with units of government, utilities, private landowners and industries to ensure the implementation of erosion and sediment control practices in conjunction with their construction and maintenance activities.

Conservation plans should be prepared for identified critical areas so that specific remedial measures can be applied to those natural or man-induced problem areas where water quality benefits warrant land treatment.

The selection for use of any one, or combination of, management practices should take into consideration site-specific conditions, costs, landowner attitudes and potential benefits.

The local management agency should place a high priority on management practices that provide the greatest benefit at the lowest cost.

Where possible, maximum use should be made of management and vegetative measures. Structural engineering solutions should only be considered where benefits outweigh costs and environmental concerns. Innovative management techniques, sensitive to conditions specific to particular sites and locations, should be encouraged.

In order for long-range water quality benefits to be realized, management practices should be maintained and monitored for extended periods of time.

Water quality programs for the abatement of non-point source pollution should be closely coordinated with other natural resource conservation programs to avoid duplication of effort and expense and to ensure maximum efficiency of all resource conservation and environmental protection programs.

A voluntary compliance approach should be established in future nonpoint source pollution control programs as a first, and preferable, management procedure.

State regulations or local ordinances should be adopted only where effective management techniques necessitate.

If regulatory programs are used, the state water quality management agency should be responsible for setting minimum standards and for overall enforcement.

If regulatory programs are used, the local management agency should be responsible for monitoring compliance and recommending enforcement action.

The toes of slopes at erosion-prone sites should be protected by vegetation or other means.

On streambanks, disturbed areas and other erosion-prone sites, vegetation should be established as early as possible and maintained continuously. For long-term protection, advanced successional woody species should be established, due to their greater root strength. In non-critical areas, woody species should also be phased into a herbaceous cover, whenever possible.

Policies restricting human and livestock activities to those which are compatible with erosion control should be incorporated with active management for protective vegetation on streambanks, disturbed areas and other erosion-prone sites.

Stream channel deepening should be minimized through methods of retarding upland runoff.

In managing for fish habitat, vegetation and woody root systems that aid in the maintenance of undercut banks, steep-sided channels and deep pools should be preserved.

Along streambanks and associated drainage areas, slope stability equations should be employed to demarcate a safe zone within which all human activity that arrests or reverts the successional process would be prohibited.

On or near slopes where surface moisture is low, surface drains and diversions should be used to control water accumulation in fissures.

Longard tubes should be considered a cost-effective alternative where shore protection is warranted. When possible, and practical, installation should be accompanied by regrading of the bluff and reestablishment of vegetative cover.

FRAMEWORK FOR LOCAL MANAGEMENT AGENCY IMPLEMENTATION OF RED CLAY PROJECT RECOMMENDATIONS

Three primary recommendations emanating from the Red Clay Project are basic to the implementation of a water quality program at the local level and serve as the foundation upon which this framework was developed. These recommendations and basic assumptions are: that soil and water conservation districts should be the local management agencies for implementing the nonpoint source pollution control portion of any future water quality programs, that soil and water conservation districts must have adequate administrative and technical staff, and that districts, as local management agencies, must have early and continuous involvement in establishing, managing and evaluating water quality programs.

The framework assumes that adequate funding is available. It is important to note that when funding is provided from outside sources (non-local management agency), conditions are usually attached which determine, in part, how the funds are expended. Elements of the 208 programs currently being developed in states across the nation would undoubtedly have an impact on the refinement and use by local management agencies of this process.

The following is a step-by-step process designed for soil and water conservation districts acting in the role of local management agencies to carry out the administrative and procedural recommendations of the Red Clay Project in an expedient manner. By following this generalized problem-solving procedure and filling in where needed with the details regarding their geographical area of concern, districts can, in essence, implement a long range program for nonpoint source water pollution abatement. The following implementation process incorporates the procedural recommendations of the Red Clay Project which can apply to all soil and water conservation districts in Minnesota and Wisconsin as well as to similar districts throughout the nation. Project recommendations relating specifically to the Lake Superior red clay area have been presented in the "recommendations" section of this report but are not included in the following framework.

STEP 1, IDENTIFICATION OF PROBLEMS AND AREAS OF CONCERN

Purpose:

The first step in this, or any, problem solving process is the identification of the types of problems that exist. Once this is done, an initial estimation of the severity of the problems should be made along with a determination of their geographical extent. The determination of the extent of the problems should include data from monitoring, research and public opinion.

When shared problems are evident, such as might exist between local management agencies within the same watershed, every attempt should be made to pool problem-solving resources. Agreements to cooperate should be established between the involved units of government and all concerned agencies. Unless justification and incentives are unique, such consortia that cross state lines should be avoided.

Actors:

--local management agencies

--other local units of government (municipalities, town boards, county boards or their committees)

--resource conservation agencies

--industries

--private landowners and land managers

--special interest groups

--interested citizens

Activities:

--gather citizen and local government input

--inventory records to determine current knowledge of problems

--survey the extent of the problems

--identify other local management agencies with similar problems

--identify a coordinating group for local management agencies with similar problems

STEP 2, DEFINITION OF PURPOSE

Purpose:

Once the problems have been identified and the geographical and managerial areas of concern have been delineated, those agencies involved must develop a system of goals, objectives and policies. It is important that a single set of goals, objectives and policies be established for everyone working on the program. This is essential where geographical areas transcend political boundaries and agency jurisdictions.

Actors:

--local management agencies

--local, state and federal units of government

--natural resource conservation agencies

--industries

--private landowners and land managers

--special interest groups

--interested citizens

Activities:

--secure cooperative agreements with involved agencies

--hire local management agency administrative and technical staff

--conduct cooperative work sessions and planning meetings

--identify work responsibilities for involved agencies and groups

--prepare goals, objectives and policies

--conduct public advisory meetings to review and, if necessary, revise goals, objectives and policies

STEP 3, INVENTORY AND ASSESSMENT

Purpose:

The third phase of the program is to prepare a detailed inventory of the resources and the problems in the affected area. This inventory process is necessary for assessing the extent and severity of the problems and will help identify critical areas and determine treatment needs. Not only should the land resource be assessed, but there should be sufficient water quality monitoring prior to implementation to determine the exact nature of the problems and to serve as a base for measuring accomplishments.

The culmination of the inventory and assessment process is the assignment of priorities to the problem areas. Critical areas which contribute the most to the pollution load of the waters must be identified and ranked according to need and treatment potential. Non-critical areas can also be assigned priority for treatment under complementary or subsidiary programs.

This entire process will require considerable manpower and time.

Actors:

--local management agencies

--resource conservation agencies

--local units of government

--private landowners and land managers

--special interest groups

--interested citizens

Activities:

--arrange for water quality monitoring by qualified personnel

--identify and map critical areas with the assistance of landowners and cooperating agencies

--set priorities for critical areas

--establish cost share rates

--conduct public advisory meetings to review and, if necessary, revise critical area priorities and cost share rates

STEP 4, SECURING LANDOWNER COOPERATION

Purpose:

An important aspect of this entire procedure is the acquisition of landowner cooperation. The most direct method would undoubtedly be the use of regulatory methods. This approach, however, does little to improve landowner attitudes, encourage cooperation or solicit effective planning and participation. One indirect method, high rates of cost sharing, may encourage cooperation, planning and participation but, again, does not necessarily improve landowner attitudes.

The development of a good conservation ethic among landowners is necessary to ensure the continued involvement of the landowner in the application and maintenance of conservation practices. Ideally, this should be done throughout the planning and implementation processes and not merely as one step in the process. From the beginning, continuous and concerted educational programs must be undertaken by local management agencies. Only through education can recusant landowner attitudes be altered and can a conservation ethic be developed which would facilitate cooperation, planning and participation and lessen the need for any regulatory programs.

Actors:

--local management agencies

--resource conservation agencies

--local units of government

--private landowners and land managers

--public landowners and land managers

--special interest groups

--interested citizens

Activities:

--initiate and maintain continuing informational programs for the general public

--sponsor educational programs to encourage cooperation from private landowners and units of government

--establish close working relationships with private and public landowners

STEP 5, PREPARATION OF CONSERVATION PLANS

Purpose:

When critical areas needing treatment have been identified and assigned priority, conservation plans for treating these areas must be drawn up by landowners and qualified professionals. Conservation plans must be directed at specific problems in critical areas and at the potentially most effective treatments for these problems. Conservation planners can not rely solely on pre-established, generalized, "best" management practices.

Site-specific considerations that must go into critical area conservation plans include: assumed efficacy of the proposed practices for each specific site, the costs of installing the remedial measures, the costs for maintaining the practices, the potential benefits to be derived from treatment, and landowner attitudes.

Actors:

--local management agencies

--private landowners and land managers

--public landowners and land managers

--resource conservation agencies

--other qualified conservation planners

Activities:

--develop alternative treatment practices

--select the most workable and acceptable measures in cooperation with landowners

--secure implementation, operation and maintenance contracts with landowners

STEP 6, INSTALLATION OF CONSERVATION PRACTICES

Purpose:

The types of practices included in conservation plans must be determined by the specific characteristics of each individual site. Efforts should be made to use innovative techniques to meet unique site needs. Managerial or non-structural control practices generally can be used more pervasively -- and, consequently, more effectively -- and at lower costs than structural treatments. In some instances, structures may be recommended where land and water use demands intensive protection. In other instances, regulatory systems, such as ordinances, may be recommended. This may be the case where livestock and human use must be restricted on eroding or erosion-prone zones.

The amount spent on the installation of a conservation practice is a function of the tradeoffs made between the greatest potential benefits and the lowest actual costs. Coupled with a strong educational program, cost sharing should be used as an incentive for program participation. It must be cautioned, again, that excessive cost share rates, because they do nothing to improve landowner attitudes, should be discouraged except in extreme problem areas where immediate treatment is needed.

Actors:

--local management agencies

--resource conservation agencies

--private landowners and land managers

--public landowners and land managers

Activities:

--provide assistance and supervision for the implementation of conservation practices by landowner

--cooperate with landowners to ensure timely and successful completion of the contract

STEP 7, MAINTENANCE OF PRACTICES

Purpose:

Local management agencies should be responsible for inspecting installations and for working with landowners to ensure their continued operation and maintenance. Policies and guidelines will have to be set to provide for inspections, to guarantee continued maintenance and to correct maintenance violations.

In addition to monitoring treatment activities on the land, water quality monitoring will have to be continued to make certain that benefits are ensuing from the applied practices. When water quality benefits are no longer derived from practices, consideration will have to be given to altering practices to meet the needs. When water quality improves to the point where remedial measures are no longer needed, alternate, less costly management practices should be used to maintain the elevated levels of water quality.

Actors:

--local management agencies

--resource conservation agencies

--private landowners and land managers

--public landowners and land managers

Activities:

--inspect practices to determine compliance and efficiency

--meet individually with landowners to encourage practice maintenance

--set policies for correcting instances of noncompliance

STEP 8, EVALUATION AND ADJUSTMENT

Purpose:

Conservation practices have to be continually monitored, evaluated and, if needed modified. The entire water quality management program should also be evaluated continually and changed if necessary. There is nothing unalterable about goals, objectives and policies. When they are no longer applicable to the problems at hand, they should be modified to reflect the current situation. The changing problems, needs, goals and objectives can only be analyzed through a continuous evaluation process.

To aid in the evaluation and adjustment of water quality programs, supplementary natural resource conservation programs can be easily and effectively tied in throughout the process. As an example, the federal Resource Conservation Act program can be used to help evaluate water quality programs or, conversely, evaluations of local water quality programs could be used as a part of the Resource Conservation Program. Similarly, local management agencies can work with ongoing Agricultural Stabilization and Conservation Service programs to set cost share rates and administer cost share programs. And as a final example, the application of conservation practices for ongoing soil and water conservation district programs can be readily tied in with the application of conservation practices for water quality programs.

Actors:

--local management agencies

--resource conservation agencies

--special interest groups

--industries

--conservation professionals

--private landowners and land managers

--public landowners and land managers

--interested citizens

Activities:

--continue collection of water quality and land management data to determine practice efficiency

--evaluate data and program operations with cooperating agencies

--establish standards and guidelines for altering ineffective practices

--seek citizen input on program effectiveness and revise, if necessary, goals, objectives and policies

STEP 9, IMPLEMENTING REGULATORY SYSTEMS (OPTIONAL)

Purpose:

Given sound educational programs and reasonable cost share rates, general program compliance and practice implementation could be achieved through the voluntary compliance of landowners. At the very least a voluntary compliance system should be used initially and then, if this fails or if certain practices, such as restricting use, necessitate, a regulatory approach could be tried.

Because of the sensitive nature of regulatory programs, local and state responsibilities must be carefully delineated. For this process, all past experiences as well as innovative techniques should be utilized. Many landowners have expressed the desire that, if needed, regulations and ordinances should be developed and administered at the local (county) level. Locally-elected officials, however, are generally hesitant to take on this responsibility, probably because of their close contact with the affected landowners.

If regulations are used, the state should set minimum standards and should be responsible for overall enforcement. Local management agencies should have the authority for working with landowners to settle disputes, supervise compliance and recommend enforcement action.

Actors:

--local management agencies

--resource conservation agencies

--private landowners and land managers

--public landowners and land managers

--county boards or their committees

--town boards

Activities:

--obtain citizen input on the need for local ordinances and in developing ordinances if deemed necessary

--develop ordinances in cooperation with county and town units of government

--establish standards, supervise compliance and make recommendations for enforcement actions

CONCLUDING OBSERVATIONS

More than four years of erosion, sediment control and water quality demonstration activities are represented in the findings, conclusions and recommendations summarized above. Some of these results belie conventional, or popularly held beliefs, views and attitudes; particularly those refining public perceptions of the nature of the red clay problem or proposing new approaches and methods. But far from all that has been accomplished was unexpected or innovative. Indeed, much project emphasis was intentionally focused on ways in which traditional land use-related institutions, procedures and techniques could be reoriented to meet the challenges posed by society's renewed dedication to clean water.

What was learned from this experiment has significance for the process of non-point source water pollution control as well as for the participants. In addition, several tools have been developed or refined during the course of the Project. A few concluding observations in these three areas are offered below as a way of further distilling the gist of the experience and relating it to the future.

Process:

Red Clay Project activities suggest that key ingredients to successful water quality management fall into three fundamental steps of the management process. As such, these ingredients become conditions or prerequisites which, on the basis of this project's experience, are felt to be needed to sustain effective programs. These conditions are grouped below as they relate to a generalized management process.

1. THOSE CONDITIONS THAT AID IN THE DEFINITION OF THE PROBLEMS AND THE GOALS:

--a problem-encompassing management institution, even if multijurisdictional

--a common set of goals, objectives and policies, even where multiple agencies and levels of government are involved

--a persistent emphasis on critical area identification and assigning priorities

--the careful involvement of a full range of inter- and intra-governmental as well as private-sector representatives

--an ongoing, continuous and broad-based educational program

2. THOSE CONDITIONS THAT AID IN THE IDENTIFICATION OF ALTERNATIVES AND THE MECHANISMS FOR SELECTING FROM AMONG THEM:

--the preparation of critical area management plans

--the matching of alternative management practices with site specific conditions and landowner attitudes

--the generation of cost-benefit and cost-effectiveness information

3. THOSE CONDITIONS THAT AID IN THE IMPLEMENTATION, GUIDANCE AND EVALUATION OF THE MANAGEMENT PROGRAM:

--the designation of a soil and water conservation body as the local management agency

--the reliance on voluntary compliance prior to regulation

--the use of reasonable cost sharing to encourage voluntary compliance

--an emphasis on local innovation and on non-structural, low-cost practices

--the use of continuous, long-term monitoring programs

Participants:

The Red Clay Project results have the potential of affecting three major groups of participants in non-point source water pollution programs in a variety of important ways. A few of the impacts which can be expected are:

Landowners and Private Interests

--increased confidence that abatement actions undertaken will have recognizable water quality payoffs

--continued assurance that society will assist with the problem through technical assistance and cost sharing

--improved participation opportunities

--expanded knowledge base through research, information and education

Local Units of Government and Their Agencies, including the Local Management Agency

--increased assurance that water quality programs are both beneficial and acceptable through planning and public participation

--greater focus for cooperative action and joint programs through critical problem identification and setting priorities

--more effective reliance on the full spectrum of management tools -- preventive and remedial, voluntary and regulatory, structural and non-structural -- through formulation of alternatives

Non-Local Units of Government and Their Agencies

--enhanced opportunity for society-wide goals to be achieved in responsive and innovative ways

--improved focus for meaningful roles in cooperation with local program partners

--increased assurance that substantial allocations of time, staff and financial resources will meet the test of cost-effectiveness

Tools:

The Red Clay Project has served to spotlight several tools of the trade that promise important dividends for water quality management. Some of these are conventional, such as comprehensive critical area erosion surveys, an open and continuous planning function, and a posture of intensive interagency cooperation. Others are refinements of existing technologies, such as the development of a solid state monitoring system for constant recording of precipitation, wind, air and soil factors at remote, unmanned sites. While still others pose unique opportunities for progressive or enterprising management institutions. The last category would include the use of zoning setback formulas for structures adjacent to critical slopes in such a way as to establish a balance between the location's erosion rate and the design life of the proposed structure. It would also include the identification and designation of safe-zone areas, or erosion conservancy zones, where all land-disturbing activities would be excluded in the interest of erosion control.

Perhaps above all else, the Red Clay experience stands as evidence that much of the foundation upon which highly complex water quality problems can be addressed may now be in place. It is possible to overcome traditionally difficult social, economic, political and institutional obstacles through a management perspective balanced by research, technical and financial assistance, and by interagency cooperation and public education. Existing federal, state and local resources, public and private, can be combined in a partnership for enhanced water quality.

RED CLAY PROJECT REPORT

by

Paul Brown, Chairman
Red Clay Executive Committee
and
Douglas County Representative

It has been my privilege to serve on the Executive Committee of the Red Clay Project since its beginning. There was a great concern before the project, if it would even be possible for a cooperative effort of five counties, several federal agencies and two states and several State agencies would even work. If the Red Clay Project proves nothing else, it proved it possible. It wasn't always easy and wasn't always fast but there was a genuine effort of cooperation between all parties concerned.

Although there are very unique characteristics of red clay which set those soils apart from many other types of soils, I believe many of the studies concerning rainfall, vegetative cover, tree cover and water action on the foot of slopes can be applied to other areas across the whole of the United States.

This was a demonstration project, therefore, different ways to resolve some of the problems of erosion were tried. I hope they all will succeed although I'm sure some will either fail or prove too costly to use over large areas of our national shoreline.

The three years have gone by quickly and I would like to thank EPA for their concern for quality water for the other generations to come. Also I would like to thank the other Federal agencies and State agencies of Wisconsin and Minnesota for their cooperation in trying to look at the many different ways of resolving some of the problems. It has been a pleasure to serve on the Committee and work with the people involved.

RED CLAY PROJECT REPORT

by

Robert Dusenbery
Ashland County Representative To
The Red Clay Executive Committee

The first Lake Superior Water Quality Conference, held in 1970, pointed out that the red clay soil entering Lake Superior through erosion was considered a pollutant.

The Ashland County Soil and Water Conservation District saw the higher lake levels, we were experiencing, accelerating the shoreline erosion process. The Ashland County Soil and Water Conservation District was concerned about the International Joint Commission Lake Levels Regulatory Controls that maintains Lake Superior at consistantly higher levels than its natural or normal fluxuations, accelerating the shoreline erosion process and degrading the water quality of this unique pristine body.

The Ashland County Soil and Water Conservation District requested the help of the Northwest Regional Planning Commission in developing testimony in opposition to the regulatory plans of the International Joint Commission and the opposition of the implementation of such plans were read into the Public Hearing Record of the International Joint Commission by the Northwest Regional Planning Commission at Sault Saint Marie, Ontario in May 1973, and at Duluth, Minnesota, in June 1973.

It was with this background of concern about shoreline erosion and its problems that Ashland County welcomed the opportunity to participate with two shoreline erosion control projects in the EPA's Red Clay Project under section 108 of Public Law 92-500.

The Ashland County Soil and Water Conservation District was disappointed in what we considered unnecessary delay in the issuance of permits to construct our projects from the Wisconsin Department of Natural Resources and the United States Army Corps of Engineers. This one year delay of construction added one year of inflation costs, thus, we were forced to scale down our projects to fit the money allocated. We also lost one year of monitoring activity.

Looking back at our involvement as Red Clay Executive Committee members, it has been a unique and exciting committee experience. These were not just a series of reports to be filed, but as committee members we got to see a number of material things in place, which I'm sure gave all of us a sense of accomplishment.

We had an excellent Project Director in Steve Andrews, an Executive Committee that was a pleasure to serve with and agency cooperation that crossed state lines that operated with a smoothness that pleased everyone involved in the Red Clay Project.

The Ashland County Soil and Water Conservation District feels confident that the answers provided by monitoring our two projects will give concerned lakeshore property owners some of the answers they are looking for in the way of cost - benefit information on shoreline protection alternatives.

Ashland County and other participating districts will carry the successful land treatment, land management practices into the water quality planning program as required by section 208 of Public Law 92-500, the Federal Clean Water Act.

RED CLAY PROJECT REPORT

by

Ila Bromberg
Bayfield County Representative To
The Red Clay Executive Committee

I served on the Executive Committee of the Red Clay Project as the delegate from Bayfield County, from funding notice in the summer of 1974 until April, 1978.

There were four Wisconsin counties (Bayfield, Ashland, Iron, Douglas) and Carlton County in Minnesota. Douglas County served as the fiscal agent and Paul Brown of that county the committee chairman. Iron County did not participate after preliminary investigation into site selection and the project in that county was aborted due to costs higher than the county could spend.

The Executive Committee selected Stephen Andrews in the fall of 1974 as Executive Director. The position was under the supervision of Northwest Planning Commission, paid for by EPA Red Clay grant funds. A secretary was hired and Donald Houtman, a former State Board Soil and Water employee assigned to the Red Clay Project, joined the staff the next year, with the approval of the Executive Committee.

I am not certain as to the exact method used to determine, on the original grant application, as to how projects were chosen for which county, as I was not a member of the Bayfield SWCD until 1974. Bayfield County tells me that the Fish Creek Watershed project (later confined to Pine Creek Tributary Watershed) was the county's third choice. Both the County and the Town of Pilsen, in which Pine Creek is located, gave lukewarm approval to the watershed re-vitalization attempt, as long as it didn't mean financial committments of any great amount.

I have been lead to believe that all counties vied for highway projects, only Carlton and Douglas being successful. This is important as counties are usually able, and willing, to contribute local shares, through County Highway Dept., for road problem areas.

MANAGEMENT

In the early months of the project, the Executive Committee, in my opinion, (myself especially included) was inept and inexperienced in both the management and technical aspects of the undertaking.

In Andrews we found a director experienced in bureaucracy and a knowledgeable geologist, so he was given carte blanche decision making by our committee. I would like to emphasize that Andrews was encouraged in this authority by the Executive Committee and, with the exception of myself and possibly Iron County, the Committee remained quite comfortable with the arrangement the four years I served on the Committee. I was forced to be the exception when my Soil and Water District strongly objected to some of the decisions approved by the Committee.

Consequently, I apparently stand alone on the Executive Committee in questioning the advisability of permitting the decisions on research, monitoring and individualized techniques, being made by management and agency people.

The EPA conducted quarterly progress reports in Superior. Technical conferences were held yearly after the proposals actively got under way. Though the Executive Committee was not necessarily discouraged from attendance, they took no active part in either the quarterly or technical conferences. In hindsight, I would recommend that quarterly and technical conferences should have been a function of, and chaired by, the Executive Committee.

The technical conferences, though extremely interesting to those involved in the project, were poorly attended or understood by the public, and we wound up pretty much "talking to ourselves."

In conclusion: my opinion is that the project was well managed, we chose an able director, with the principal critique that the committee willingly abdicated their authority.

RESEARCH

A giant chunk of grant money went into research projects concerned with Red Clay soils and the flora and fishlife found in association with clay soils. The researchers were "local" (Superior and Duluth) which had the decided advantages of both accessability and good public relations. They all appeared to be competent professionals.

It is probably too early to assess the value of each research to future goals of soil and water conservation but this is an aspect that, hoepfully, will be carefully scrutinized.

I have seriously questioned the relationship of several of the research programs in soil loss corrections. In my opinion, Dr. Joe Mengel of UW-Superior, has done the most comprehensive work on red clay associated soil types. Most of his research was complete before the Red Clay Project's inception and was available for our use in various aspects of the program. His formula for predictability in slope stabilization (or failure) is well accepted professionally and an excellent guide for both the professional and layman.

One fishery's research was being pretty well duplicated by the Wisconsin DNR. It is difficult to foresee all duplications in research but, in future grants, care should be made to avoid parallel expenditures.

Two aspects of research have produced some surprises and could be of value to other agencies in unexpected ways--

1. Dr. Olson (UMD) has invented, for the astonishingly low sum of about $10,000 a rain guage with a memory that records both the daily precipitation, the time of day and the force of rainfall.

2. A plant association study (UW-Superior) has revealed a vast difference in understudy forest growth between aspen rejuvenation and mixed hardwoods which suggests an unknown chemical content in Aspen. My local county and DNR foresters are very interested in the study results; the research may prove more relavent to foresters than to soil management.

COUNTY PROJECTS

IRON COUNTY declined participation although Marvin Innes of Iron County remained active on the Executive Committee.

The proposed structure on Spoon Creek would have been interesting in that it was to be somewhat different from any other structure. A dam to operate as a flood water deterrent, was to be constructed below the confluence of two ephemeral branches. At our on-site tour in September 1974, a colony of beaver were in process of construction of a sizeable dam on the west branch of Spoon Creek. A SCS employee remarked that we could sink a small fortune into a man-made dam or protect the beaver and get it done for nothing.

DOUGLAS COUNTY opted on two ingenious structures, one about one-quarter mile or so below the other on a spring fed stream (as well as farmland improvement, etc.).

I've no comment, except that time will tell whether either (one much more costly than the other--but both expensive) will be a practical erosion tool. The costs would appear prohibitive, unless the protection is of some property of value.

ASHLAND COUNTY'S projects have been unique in that both involve local Indian interests. The Madeline Island site is a somewhat conventional structure, mostly under water, that was built to protect a very unusual historic cemetary. The cemetary contains the remains of Chief Buffalo, the handsome Chippewa who was the model for the bronze busts that adorn both the U.S. Senate and the U.S. House of Representatives buildings in Washington, D.C.

The Longard tubes installed on Madigan Beach (Bad River Indian Reservation) are the envy of every Wisconsin County participating in the project and are being monitored with interest. Relatively inexpensive as shoreline structures go, if successful as a beach builder, it has real practical potential. The bank above the tubes, except for a small section of access, was left untouched, is almost perpendicular and eroding badly. Until this bank reaches an angle of repose (if it does) it threatens the success of the tubes. In retrospect, it is regrettable that one section of beach was not stabilized before the placement of tubes for comparison of results. If the tubes do fail, it would be my suggestion "try again."

The survival of both Ashland projects are somewhat dependent on the Corps of Engineers' (sanctioned by IJC) future decisions on the level of Lake Superior. If the water level continues to inch upward, the structures may not have been given a chance, if failure does occur.

CARLTON COUNTY'S participation has been the most diversified. The State of Minnesota supported the project with monies that have allowed varied demonstration of structures as well as a diversity of farmland practices.

It has also been the county plagued with tragedy, with the failure of Elim Dam and roadside banks collapsing before the end of the project.

Since Dr. Mengel (UW-S) had, previous to the Red Clay project, developed a formula to determine slope angle needed to achieve stability, the judgment of the SCS engineer who formulated the structures' plans, is decidedly questionable.

If we learn nothing else from the Carlton County experience, we find we can't out-engineer Mother Nature.

BAYFIELD COUNTY - The original grant request would have, hopefully, been sufficient to stabilize the farmland soils in the Fish Creek Watershed. The area is large and the soil problems serious so the Pine Creek branch was selected with 49 farms involved in the watershed. The SCS selected about 2 dozen farms in need of farmland practices that should improve water quality; the remainder considered land already adequately treated.

Bayfield County SWCD approved the plans, with a stipulation that a bank slide on North Fish Creek just above the confluence with Pine Creek be stabilized. The Town of Pilsen also agreed to cooperate and were particularly insistent on the bank stabilization as they were in danger of losing a Town road to the slippage. (Before the 1946 flood the river channel had not undercut the hillside).

Almost immediately the project ran into difficulties, especially with the Wisconsin Department of Natural Resources, who either did not wish to cooperate or were plagued beyond belief with inefficiency.

SCS helped farm owners apply for the needed permits and the project arranged a day (Sept. 1974) specifically for DNR personnel to inspect the Fish Creek and Spoon Creek sites. The only DNR person to show was Cy Kabat of Madison; Spooner ignored the engagement until Kabat gave verbal approval (by default of the Spooner office) at which time the stuff hit the fan.

If it was DNR's intention to sabotage the project, they did it well. The farm participation dropped to 9 landowners as DNR red tape and lack of cooperation brought practices to a halt. Requests for permits were ignored as were letters by other agency people. Only the interference from elected people brought results and then one step at a time. The permits took from 7 months to 3 years. Two structures requiring permits were dropped from plans but we left the requests in to see how long it would take if the applications for permits were not pursued. It has been over 3 years, and as far as I know no response has ever been made by DNR. This is not that all individuals in DNR were uncooperative; some people in the Brule office really tried to be of assistance.

The slide on North Fish Creek ran into more difficulty than that caused by DNR lack of cooperation. Neither agency nor management people felt that the hillside could be stabilized without some question of success. The cost estimate of $8,000 grew to $80,000, necessitating county dollar involvement beyond which Bayfield County was willing to pay.

Three monitoring stations had been installed (one later removed). The cost to USGS for monitoring Pine Creek mushroomed from $58,000 to $129,000, which infuriated local officials. A severe drought in 1976 and the abandonment by farmers in participating in the project rendered most of the monitoring useless. When the contract with USGS was signed there was no written provision which would have required USGS to supply the project with a written evaluation of the monitoring, and they have refused the evaluation unless more funds were provided (which was denied by the Executive Committee).

On the plus side, the farmers who did participate seem well pleased with the practices and structures made possible by the EPA grant. I am sure they are sincere in their stated committments that the practices agreed to will continue and that the advantages of good soils management will be broadcast the best means possible--Example.

Note: In 1977 the U.S. Supreme Court ruled that government agencies, operating with federal monies, are not required to obtain state and local permits. The Corps of Engineers did issue the permit required for the Fish Creek structure earlier this year.

SUMMARY

One thing that the Red Clay Project was supposed to ascertain whether agencies could cooperate across state lines as well as with each other. Considering the complexity of such an undertaking, the experiment seemed to work well.

With the exception of the Wisconsin DNR all agencies I have mentioned, as well as UW-Ext. and the Dept. of Transportation, made a sincere effort to work together. There were problems but the desire to cooperate was not one of them.

Soil Conservation Service played the major role as technical advisors, and except for the criticism previously alluded to in Carlton County, did an excellent job. Statewide, from the state conservationist down to field technicians, I found the service to be highly capable professionals.

It is regrettable that the "remains" of perhaps the most important agency was never actively involved in the Red Clay Project--the old Red Clay Interagency. No longer a group, the individuals could have been a real asset in the adventure. We owe them a great deal, not only in the first demonstration project of this type, which they accomplished literally with pennies (Whittlesly Creek in Bayfield County) but by the instigation to do something about roadside erosion and seeding. They also made possible the grant to fund us. I regret they did not participate actively; nor do I know why they did not. But I would like to salute those of the old group that I personally know: Cy Kabat, George Wright, Chuck Stoddard, Garit Tenpas - "Without you, there would have been no Red Clay Project."

At the time that the Executive Committee voted to add a State Board SWCD member (Houtman) to the Red Clay staff, I, alone stubbornly voted "no". My advice came from locals and other agency people, whose reservations were not against the individual but the State Board having an "inside track". I am pleased to admit that I was wrong in my vote. I feel that the State Board staff is exceptionally efficient, attuned to local governments and will play a very effective role in the nuts and bolts part of the Clean Water Act--if SWCDs will support them. I have found a reluctance, which I do not agree with, on the part of Districts, and some agency people, to support the State Board as I feel that they should; this reluctance seems based on a fear that the Board will become a competitive agency, too strong, and will lose contact with local interests.

Consequently, by not giving statewide support to the Board, a great chunk of the authority in Wisconsin of the Clean Water Act is being exercised by the Wisconsin DNR, over whom local interests have never and will never have any influence.

If the SWCDs in Wisconsin are to have any influence over the land use regulations that will, without doubt, accompany Clean Water funding, in my opinion, they are going to have to give more support to the State Board and staff, including an increase in staff across the state--then be interested and concerned enough with both good soil practices and clean water to get involved.

WHAT DO I THINK THE PROJECT HAS PROVEN?

Positively, that most of the practices on both farmland and in structures will no doubt work.

Negatively, that cost factors we encountered are probably going to be so excessive as to be totally impractical if applied statewide and under the cost sharing ratios used in the Red Clay Project.

I don't believe that either land use regulations and/or cost sharing on a giant scale will ever accomplish the job the Clean Water Act mandates; the costs would be too high. But if the legislature can be convinced to provide incentives, such as tax breaks, to volunteer landowners and funds can be made available (SCS) for technical assistance, we improve our chances of making progress, though the 1980's as the deadline for potable water is unrealistic.

RED CLAY PROJECT REPORT

by

Gerhard Oltmanns
Carlton County Representative to
the Red Clay Executive Committee

As I look back on nearly four years of the Red Clay Project, I will have to pick the good from the not-so-good.

First, it was a pleasure working with the Red Clay Committee and the various agencies, some of which I did not agree with or think necessary.

Part one of the Red Clay Project was a huge success. This was composed of many parts, listed under Upland Treatment. Some of these were as follows: pasture management, fencing cattle from hillsides and streams to prevent erosion, waterways - both rock and grass, stock-watering ponds, seeding roadsides and gullies to prevent erosion, small sediment dams that control water run-off, and rock gabions in wash-outs.

The Highway 103 project was a success except for a few slides, which are only a small part.

The not-so-good part is the Elim Dam and the Hanson Dam. The excessive amount of rain is one reason these dams are not finished. Had we known a little more about red clay soil at the beginning, these also might have been finished. This was a pilot project, and many things can happen.

All in all, the Red Clay Project has enlightened many people, and taught us all much about how to stop or prevent soil erosion.

RED CLAY PROJECT REPORT

by

Marvin Innes
Iron County Representative To
The Red Clay Executive Committee

Iron County occupies the east boundary of the Red Clay Project area. Erosion and sedimentation from our red clay soils is a main problem here as it is throughout the area. And, for this reason, it is regrettable that Iron County could not have played a more <u>active</u> <u>role</u> in the Red Clay Project.

The Iron County Soil and Water Conservation District's original proposal was for the construction of a flood water retarding structure on the Oronto River/Parker Creek at Saxon Harbor on Lake Superior. Cost estimates were deemed too high for this project.

The second proposal called for the construction of a debris basin on Spoon Creek. This, too, ran aground when cost over-run problems were encountered. Iron County sought other methods of funding but none were found available. As a result, this project was also abandoned.

At this point the Iron County SWCD, working with the Red Clay Project staff and other cooperating agencies, tried to identify other possible projects. These were discovered to be either duplicates of on-going projects in other counties or did not meet project criteria. Another problem was trying to design suitable projects but at a cost feasible for Iron County to participate.

In light of this the Iron County SWCD elected to withdraw from active participation in the Red Clay Project. However, the county's SWCD did continue to support the Red Clay Project and the programs which were developed in the other four counties. A member of the Iron County SWCD also remained active on the Red Clay Project's Executive Committee.

During Iron County's participation, a little over $38,000 of project funds were utilized in the county for preliminary engineering, surveying and roadside seeding on 1.5 acres of road-side. The county's University Extension staff also contributed to the Informational and Educational (I & E) efforts of the project.

Although Iron County's role in the Red Clay Project was limited, the county's SWCD did appreciate the opportunity to work with the Red Clay staff, the SWCD's from Ashland, Bayfield, Douglas, and Carlton counties, and all of the agency personnel involved with the project.

REPORT TO THE RED CLAY PROJECT

BY THE WISCONSIN BOARD OF SOIL

AND WATER CONSERVATION DISTRICTS

By

Donald S. Houtman*

The Wisconsin Board of Soil and Water Conservation Districts was instrumental in establishing the Red Clay Project. Through its field representative working with the involved soil and water conservation districts, the state board encouraged and assisted the formation of the project by the districts. The field representatives were particularly effective in helping the districts secure a grant from the U.S. Environmental Protection Agency to partially fund the proposed erosion and sediment control program.

In April of 1974, the state board opened a field office in Spooner, Wisconsin in order to work more intensively with the districts in northwestern Wisconsin. The board's representative in this office worked closely with the districts and the cooperating agencies in planning the project. The primary agencies involved in this stage of the project were the Northwest Wisconsin Regional Planning Commission (principal participant and recipient of an $80,000 grant from the Upper Great Lakes Regional Commission for preparing a Red Clay Project grant proposal and work plan). The Pri-Ru-Ta Resource Conservation and Development Project (Wisconsin), the Onanagozie Resource Conservation and Development Project (Minnesota), the Arrowhead Regional Development Commission (Minnesota), the Minnesota Soil and Water Conservation Board and the Wisconsin Board of Soil and Water Conservation Districts.

The Red Clay Project began operations with the approval of the funding grant and the opening of a project office in Superior, Wisconsin. The state board field representative in Spooner continued working on the project and supporting the sponsoring districts in Wisconsin, devoting from 25% to 50% of his time as "in-kind" services during 1974 and 1975.

Through the efforts of the board representative in Spooner, an agreement was reached with the project for the state board to supply specific services to the project and the sponsoring soil and water conservation districts. In October of 1975, the state board signed a contract with the Red Clay Project to provide the position of project specialist. The board representative stationed in Spooner assumed this position. The new representative in the board's Spooner office and Madison-based board staff continued to provide " in-kind" support for the project at a level comparable to that which existed prior to the creation of the project specialist position. The duties of the project specialist were listed in the contract between the board and the project. In essence, the specialist served as assistant to the director and staff to the project. The only full-time project staff housed in the projects' office were the director, the specialist and secretarial support. Others working on the project were responsible to different agencies and were not considered project staff.

There were two phases of the Red Clay Project in which the project specialist had reportable responsibilities: the information and education program and work with the sponsoring soil and water conservation districts. In addition to these activities the project specialist, in association with other state board staff, initiated several educational and information-gathering programs related to the overall goals of the project.

INFORMATION AND EDUCATION PROGRAM

The information-education program was set up primarily to facilitate project operations and to help achieve the goal of promoting proper land management within the project's geographical area. The principal participants in the development and operation of the education program included representatives from the University of Wisconsin-Extension, the University of Minnesota-Extension, the University of Wisconsin-Superior, the University of Minnesota-Duluth, Northland College, the Wisconsin Board of Soil and Water Conservation Districts and project staff. A central committee composed of representatives of these agencies was formed to oversee the educational program. Project-wide activities including conferences, tours, workshops, public meetings, newspaper specials and exhibits were conducted under contract with the University of Wisconsin-Extension with the assistance of the above-mentioned agencies. Other project-wide activities including tours, conferences, news media reports and specials, newsletters, brochures, slide-tape sets, exhibits and photographs were produced by the project specialist with assistance from cooperating project and agency personnel.

A considerable amount of latitude was given to the local sponsors in conducting those portions of the information and education program affecting citizens within their geographical boundaries. While an overall plan for the information and education program was developed which included a timetable for the implementation of these local activities, the project managerial attitude was such that provisions were not made for the coordination and implementation of these activities. In other words, central direction for the implementation of local activities was not necessarily provided by project management nor authorized to be provided by the project specialist, project staff or other involved participants. Consequently, without central direction or coordination, many of the local (county-wide) workshops, public meetings, field tours and other citizen-contact occasions were not as effectively implemented as they could have been. This, in turn, undermined, or at least did not serve to strengthen, local support for the project and the water quality and land management goals of the project.

The central, or project-wide, information and education activities fairly well followed the initial plan and can be considered to have been successful. Conferences were held annually as planned to review the status of the project for concerned professionals and interested public. Except for the final tour, no project-sponsored, planned tours were conducted. Numerous, well-attended tours, however, did take place not as planned project activities but, rather, in response to requests from different groups or to meet specific needs. Radio, television and newspaper coverage of the project occurred in response to efforts of the project staff and in response to specific news items. No radio or television specials were prepared, but several newspaper specials were written by project staff and cooperating agency personnel. A newsletter was published on an as-needed basis which nearly worked out to be quarterly. Several presentations on the project were given to special interest groups upon request. An introductory and a concluding brochure were prepared and distributed. One slide-tape set was prepared and used with presentations and exhibits. Several exhibits were prepared and used at major events throughout the project area and the two states. Rather than having one prepared exhibit, the exhibit format was prepared and the content was modified to meet the needs of individual situations.

In summary, the information and education program was successful at informing local, state, national, and in some instances even foreign individuals, agencies and interest groups of the project and its accomplishments. The several components of the program (tours, conferences, newsletters, etc.) were put together in a way that met the needs of the project and those interested in the project. The one shortcoming of the program was in not being able to most advantageously meet the informational and educational needs of landowners who were potential project participants. For this, a system of individual or, even better, small group (5-6 individuals) meetings would have to have been built systematically into the information and education program.

SOIL AND WATER CONSERVATION DISTRICTS

A major component of the project specialist's position was to work with the sponsoring soil and water conservation districts to assist them in their role as sponsors and to help them prepare for future nonpoint source water pollution abatement programs. Work with the sponsoring districts involved assistance with district program development, district participation in the project, the Bayfield County/Pilsen Township sediment control ordinance development, a red clay area streambank and roadside erosion survey and the development of guidelines or a framework for district participation in future erosion and sediment control programs.

District Program Development and Project Participation

Prior to the onset of the Red Clay Project, the soil and water conservation districts in the project area generally were not considered to be the most active and most involved districts in the two states. This probably was due not to any inactivity on the part of individuals but, rather, to the fact that these were not highly agricultural areas and district programs in the past traditionally were associated with agricultural concerns. Because of this, relatively weak, inactive districts evolved in the five-county project area. The descriptive terms of "weak" and "inactive" refer to the number and regularity of meetings held per year, the number and type of business items discussed at meetings, the number and types of programs in which they were involved, and the subjectively-assessed level of interest displayed by supervisors and cooperating agency personnel.

After the start of the project and probably as a direct result of it, there was a noticeable increase in nearly all of the five districts' activities. This resulted not only from a need to manage the project in their own counties but also from a change in the perception of the role of a soil and water conservation district. With the project there was a realization that districts need not be involved in only agricultural activities and doors were opened to other fields of natural resource conservation.

In working with the districts on program development, the tools of the Red Clay Project were used to set examples for the districts and to help motivate them. For example, a project-wide newsletter was published which featured activities and programs of the districts as well as project events. Many project meetings were structured to involve districts and to provide examples of preferred meeting formats. Much was done to help publicize the districts' programs through presentations at area and state meetings and through the use of exhibits, displays and the audio-visual materials. In addition, considerable assistance was given to districts in their planning, reporting and other on-going activities.

In general, the sponsoring districts have experienced success in their program development through participation in the Red Clay Project. This success, however, is limited. While there is an increased awareness of natural resource concerns and a desire to preserve the existing high quality of these resources, natural resource conservation is still not an item of high priority in these counties. Consequently, limited county funds and manpower resources are not directed toward those areas of relatively low priority, including soil and water conservation. The need for increased soil and water conservation is not uniformly perceived and maybe, in this area where many of the erosion problems are natural phenomena not directly related to man's current activities such as farming, this perception is justified.

Bayfield County/Pilsen Township Sediment Control Ordinance

The work plan for the Red Clay Project called for the development and implementation of a sediment control ordinance in that portion of Bayfield County involved in the Red Clay Project. This, apparently, from discussions with supervisors and cooperating agency personnel, was put in the plan against the advice of these same supervisors and agency representatives. According to these representatives of the soil and water conservation district, there was no need to impose regulations on landowners of Pilsen Township where, in their perception, man's land-disturbing activities had very little effect on the sediment load of the area streams. Furthermore, if the project was to explore the use of regulations, the district representatives felt that this should be done in the Lake Superior shore area of the county where increased tourism and development was expected.

Given this background and these underlying attitudes, it is not surprising, then, that there was little support at the district level for the development and implementation of a sediment control ordinance in Pilsen Township. The district did approve the Red Clay Project work plan which included a provision for the Pilsen Township ordinance. However, it was made obvious when work was attempted on the development of the ordinance that they approved the plan reluctantly.

At a meeting of the Bayfield County Soil and Water Conservation District, approval was given to the project to start work on the development of a sediment control ordinance. However, the supervisors did not agree to actively participate nor did they request any of their cooperating agency personnel to participate. In other words, they would let the project staff work on it but offered considerable resistance through nonparticipation. The authority to develop and implement sediment control ordinances in Wisconsin lies with the soil and water conservation districts and the county boards. In order to be successful, any such ordinance would have had to have been prepared with the close cooperation of the district, the county board and the township. This willingness to participate and cooperation never evolved.

Some work was done by the project specialist with residents of the township to explore the idea of developing and implementing an ordinance. Suprisingly, the landowners exhibited more of a willingness to work on this than did the elected officials. They tended to realize that if water pollution abatement programs were going to work, some type of regulations would have to be used. The elected officials at the county level, however, may have realized this but did not want to be in the position of having to enforce an ordinance. After this initial contact with township landowners, project staff were requested by a few district supervisors to stop all further work on the development of the ordinance until further notice. Apparently there was some trouble between landowners in the red clay area of the county and the county zoning committee and these supervisors felt that further talk of ordinances and regulations would additionally aggrevate an already volatile situation. Work was halted in accordance with the supervisors' request and no further notice was given by the supervisors to resume work on this program.

Experiences with this attempt to develop a sediment control ordinance under existing Wisconsin state statutes have not been all negative. One positive insight gained from this portion of the Red Clay Project is the realization that landowners may not be as averse to accepting land management regulations as one might initially suppose. Landowners, generally, did express the attitude that if water quality goals were to be met, regulations of some type would be needed. The unanswered question, however, is, Are water quality goals reasonable and worth achieving? Landowners also, generally, expressed a willingness to work on the development of needed regulations, realizing that if the people affected by the regulations were involved in developing what went into them, the regulations would be more meaningful and effective and would stand a better chance of being complied with.

Another observation derived from work on the sediment control ordinance involves the vital role played by state regulatory agencies. In Wisconsin, there is considerable criticism expressed by local elected officials toward the state natural resource regulatory agency, in this case, the Department of Natural Resources. The criticism usually centers around the need for permits for activities affecting navigable waterways, the time consumed in obtaining permits and, generally, the regulatory nature of the governance of such activities. However, if the state agency (DNR) were not to assume this function, one likely alternative would be for regulations to be enforced at the county level. The experience in Bayfield County has indicated that this is not a preferable alternative. Consequently, in spite of the criticism of the

Department of Natural Resources,that agency is performing a vital regulatory function relieving local officials of this onus and allowing them to work more harmoniously with landowners in their counties.

Streambank and Roadside Erosion Survey

Prior to direct involvement with the Red Clay Project, the Wisconsin Board of Soil and Water Conservation Districts was preparing a proposal to survey the extent of erosion along streambanks and roadsides in the Wisconsin portion of the Lake Superior basin. Local support for this project was obtained and different sources of funding were explored.

Funding was not obtained through these sources. After the state board entered into a contract with the Red Clay Project, the proposal was presented to the project for consideration. The project agreed to conduct the program but, because of several limitations, it was modified to work only in the red clay area and to include Minnesota as well as Wisconsin, to include a survey of the extent of existing information on streambank and roadside erosion, to complete the roadside erosion survey and to conduct only a sample survey of streambank erosion.

This program was conducted by the Red Clay Project under contract with the University of Wisconsin - Superior and is reported on elsewhere in this report. The information compiled through this project is made available to districts and other local conservation agencies through the district offices, the University of Wisconsin - Superior and the Board of Soil and Water Conservation Districts. It is essential information for understanding the existing state of streambank and roadside erosion and the amount of current control work. It is also essential data for planning and conservation program development.

Framework for Implementing Red Clay Project Recommendations

In the contract between the project and the state board, one of the primary responsibilities of the state board was to develop a mechanism for presenting the findings of the Red Clay Project in a manner that could be readily used by soil and water conservation districts and other agencies and units of government which could conceivably be designated as local management agencies for erosion and sediment control programs. This objective of the state board was established to help the sponsoring districts gain increased management potential from their Red Clay Project experiences. It was also established to help meet the project goals of developing a " .... long-term, basin-wide erosion and sediment control program," and developing and assessing"....institutional arrangements for implementing basin-wide programs for erosion and sedimentation control."

A list of twenty-eight recommendations were generated by the Red Clay Project. These were derived from the research and demonstration work done by the project and from the experiences gained in the management of the project. Based on these recommendations, an eight-stage framework was developed which could be used by districts to implement a comprehensive erosion and sediment control program. This framework addresses the major implementation concerns, the necessary actors and activities, and the temporal sequence of activities in implementing a control program. This framework encorporates all of the recommendations of the Red Clay Project. The recommendations and the framework are presented in the final summary report of the Red Clay Project entitled: Impact of Nonpoint Pollution Control on Western Lake Superior: A Summary Report.

*Red Clay Project Specialist with the Wisconsin Board of Soil and Water Conservation Districts

RED CLAY PROJECT INFORMATION AND EDUCATION PROGRAM

Services Contracted with University of Wisconsin-Extension

by

Raymond E. Polzin*

The Douglas County Soil and Water Conservation District, acting as fiscal agent for the Red Clay Project, on February 9, 1976 contracted with University of Wisconsin-Extension for certain information and education services. It was the intent of this agreement that UWEX in cooperation with the Red Clay Project staff, involve representatives of University of Wisconsin-Superior, University of Minnesota-Extension, and the Sigurd Olson Institute of Northland College in educational activities to be conducted in the five county area for the duration of the Project.

Included in the contract developed by the Project staff and University-Extension were listed specific activities to be carried out. While the spirit of the agreement was followed, variances in the plan developed as the staff perceived changing needs and opportunities. It became apparent that different audiences had different expectations from the Project and different levels of understanding about the techniques being demonstrated.

Local officials, for example, at early stages of the Project expected funding to carry out erosion abatement in areas which they considered critical. Environmental groups at some points were critical of the locations and methods chosen for demonstrations. It was necessary to explain again and again that the Environmental Protection Agency was funding the Project to determine cost effective methods of improving water quality. Much of the effort of the Information and Education Program was aimed at gaining this understanding.

Monthly meetings of the five-county executive board provided an opportunity to assess the level of understanding regarding the Project. In addition to District Supervisors, the participants were agency representatives and concerned citizens. These board meetings frequently offered opportunities to provide correct information to the media.

I & E ACTIVITIES

A variety of activities and methods were employed to bring the public information about the Red Clay Project. These activities will be briefly described.

Public Meetings

As the Project began it was necessary to meet in each of the counties with landowners and local officials. These meetings arranged by County Extension Agents gave an opportunity to review background information and present the Project staff and agency representatives to outline plans for the area. These face-to-face presentations helped to correctly interpret the intent of the Project. As the Project progressed, additional meetings in some communities helped to encourage landowner participation.

Physical Models

In order to involve young people of the areas a plan to construct physical models of target watersheds was conceived. William Lontz, Area Extension Environmental Specialist, worked with an ecology class at Superior Senior High School in building a scale model of the Little Balsam watershed. A second model of the Pine Creek watershed was completed by a class at the Ondassagon High School.

In addition to developing an interest in local geology and the Red Clay Project, the completed models were used as exhibits at fairs and in public meetings.

Tours

Tours ranged in scope from the two hour visit to a construction site to the two day final tour in August of 1978. In most cases the tours did not attract the general public but they provided an opportunity to involve the media with on the spot coverage of Project activities. Since many of the construction sites and land treatment sites were not very accessible, the organized tours provided a chance to visit these locations.

Exhibits

The Project staff was directly involved in the preparation of exhibits for several events. Materials were provided by all of the agencies working on the Project. Extension agents arranged for photo exhibits plus physical models at fairs in all five counties. These exhibits were also used at report conferences, SWCD conventions, and other field days.

Newspaper Reports

Local newspaper coverage of major Project activities was quite satisfactory. Reporters were involved in tours and conferences. Local papers also made good use of releases by Extension agents and other agency people. Newspaper specials and coverage of the Project by large newspapers was somewhat disappointing. The Agricultural Journalism Departments of both the University of Wisconsin and the University of Minnesota assisted with write-ups but were not very successful in getting published in the large regional publications.

Non-Point '83

Extension agents used a slide set developed to tell the Red Clay story to a number of audiences. When the film "Non-Point '83" was released it became a useful tool in explaining the intent of the Project.

A study guide was developed for use in a classroom situation. The guide was pre-tested in both university and high school classes.

In a special effort with the schools of Bayfield, Ashland, and Iron Counties, the Sigurd Olson Institute used the film with the study guide in sixteen classroom presentations.

Conferences

It was the responsibility of University-Extension to arrange for annual report conferences. Physical facilities of the University of Wisconsin-Superior and Northland College were made available for these events. Attendance at these events was largely the principle investigators and representatives of the agencies involved in the Project.

Civic Organizations

Presentations on the Red Clay Project were made to service clubs, farm organizations, community clubs and other civic groups. Extension agents, Project staff, and Soil Conservation Service personnel participated. The film "Non-Point '83" or the Red Clay slide set were frequently used to stimulate thought and discussion.

Television Coverage

Three local television stations filmed Red Clay Project activities at different times. It seems that the most dramatic activity of the Project was the installation of the Longard tubes on the South Shore of Lake Superior. This has received television coverage from time to time.

Radio Programs

Radio coverage of Red Clay Project activities was carried out primarily by Extension agents on their regular radio programs. This investigator conducted one half hour interview on Station WWJC.

SUMMARY

All information and educational activities were carried out in cooperation with the Project director and staff assistant. Since this investigator also served as secretary to the five-county executive board it was possible to assess at monthly intervals the need for additional educational effort. While the educational effort was not aimed at a massive program with the general public it was designed to provide current and correct information to all who "needed to know". Educational materials such as the brochure, newsletters, exhibits, etc. developed by the Project staff were most helpful in the educational effort.

In conclusion, the cooperation of Steve Andrews, Project Director, and Donald Houtman, Project Assistant, was much appreciated. Special mention must also be made of the significant planning assistance given by Arnold Heikkila, University of Minnesota-Extension, and William Lontz, University of Wisconsin-Extension. County Extension Agents David Radford of Carlton County, Harry Lowe of Bayfield, Dwaine Traeder of Ashland, and John Koch of Iron, are all to be commended for the leadership given in their respective counties.

*Douglas County Agricultural Agent with the University of Wisconsin-Extension

NACD CONTRACT WITH RED CLAY PROJECT

by

William J. Horvath
North Central Regional Representative, NACD

On March 21, 1973 following a telephone conversation with Carl Wilson, Chicago Office, Environmental Protection Agency, about Section 108 of the Water Pollution Control Act of 1972, meeting arrangements were made by Vernon Reinert, then the Regional Representative for the State of Wisconsin, Board of Soil and Water Conservation Districts and the NACD North Central Regional Office.

The meeting was held at the Central Wisconsin Airport, Mosinee, Wisconsin on March 30, 1974. The purpose of that meeting was to explore a Section 108 grant in the Red Clay area of Wisconsin.

Attending that meeting were representatives of Soil and Water Conservation Districts in Wisconsin and Minnesota and state and federal agencies interested in the Red Clay area problems. Also in attendance were Carl Wilson, Ralph Christensen and Fred Risley of Region V, EPA. A four hour exchange of information and discussion on Section 108 demonstration grants ensued.

Out of this discussion evolved what is known as the Red Clay Project and the EPA Section 108 demonstration grant to five county soil and water conservation districts in Wisconsin and Minnesota. And out of this meeting grew the idea for film on nonpoint pollution.

NONPOINT '83 FILM CONTRACT

Following is the sequence of events relative to production of the film:

June 6, 1974	Contract was made with film producers on possible cost of film.
March 5, 1975	Justification for the film on non-point pollution control submitted to Red Clay Project Office.
September 3, 1975	First meeting with Steve Andrews, Red Clay Project Director on film contract.

October 2, 1975	First meeting with Robert Burull, Director of Telecommunications on possible film contract with the University of Wisconsin-Stevens Point.
October 9, 1975	Technical Advisory Committee meets with film producer to outline objective of the film. Permanent Advisory Committee composed of Carl Wilson, EPA; Steven Andrews, Red Clay Project; Leo Mulcahy, Wisconsin State Board of Soil and Water Conservation Districts; Rich Duesterhaus, SCS, Washington, D.C.; James Lake, Black Creek EPA Project.
December 8, 1975	Final contract for production of the film completed.
December 22, 1975	Steven Andrews approves contract between NACD and the University of Wisconsin-Stevens Point.
January 6, 1976	NACD enters into formal contract with University of Wisconsin-Stevens Point for film production.
January 26, 1976	NACD enters into formal contract with Red Clay Project.
February 27, 1976	First installment paid to film producer per contract.
March 31, 1976	Inventory of possible film site selections is completed.
July 1, 1976	Second installment paid to producer on acceptance of film script.
August, 1976	Producer begins shooting footage for film in various locations across country.
April 20, 1977	Technical Advisory Committee meets to review film footage shot and changes in script.
June 15-16, 1977	Technical Advisory Committee meets to review all footage shot and.approve final film script.
July 19, 1977	Third installment paid to producer for completion of filming.

September 14, 1977	Technical advisory committee reviews answer print.
October 31, 1977	Red Clay Executive Committee reviews answer print and gives approval for additional copies.
November 8, 1977	Special showing of film to EPA staff, Chicago.
November 28, 1977	Fourth installment paid to producer upon approval of interlock screening.
December 14, 1977	Special Preview Showing of film in Washington, D.C. to over 400 people from environmental agencies and other organizations.
December 22, 1977	Prints of film delivered to NACD and EPA Red Clay Project from Gordon Lab per contract.
December 28, 1977	Promotional brochure on film delivered per contract to Red Clay Project Office, EPA, and NACD.
February 6, 1978	Film shown to 2000 district officials at national convention in Anaheim, California.
February 26, 1978	Videotape copy of film and 15 second film clip for use on TV delivered to NACD and Red Clay Project.
March 1, 1978	Fifth installment paid to producer for completion of project.
March 1, 1978	Contract amendment and final payment made to NACD.

The contract between the Red Clay Project and NACD called for a $62,200 project of which 75% or $46,650 would be federally funded and 25% or $15,550 in costs would be services performed by NACD.

The contract as written called for four items:

1. Deliverance of a full length 27½ minute color film on nonpoint pollution.

2. A finished 3/4 inch videotape of 25 minutes duration suitable for cable broadcasting.

3. 1,000 copies of suitable promotional material on the film.

4. Two film clips on nonpoint pollution suitable for use on TV.

In fulfillment of this contract, NACD:

1. Delivered five prints of the film for use in the Red Clay Project area, 10 copies for use by EPA Regional offices and 10 copies to the NACD Film Library for rental purposes to NACD's 3,000 member districts.

2. Delivered a 3/4 inch videotape for use in the Red Clay Project area TV stations.

3. Delivered 1,000 copies of a promotional brochure on the film to the Red Clay Project Office for use in the area. In addition, NACD mailed its 24,000 copies to districts, others who use NACD's Film Library, and other film libraries.

4. Delivered 2 copies each of two 15 second TV clips suitable for use on TV stations in the Red Clay area. In addition, 8 copies of each of the two film clips (one of which deals with conservation tillage and the others with irrigation) are in NACD's Film Library for districts' use in their education programs.

NACD FILM - VIDEOTAPE PROJECT OBJECTIVES

As established by the Technical Advisory Committee at their first meeting on October 9, 1975, the film and videotape would be produced to fulfill the following objectives:

<u>General</u>

1. To identify and relate content to Public Law 92-500, Section 108.

2. To illustrate and identify nonpoint source polluting areas as they affect the quality of water with emphasis on farming, but including silvicultural and non-agricultural.

3. To illustrate the effects of nonpoint source pollution on water quality.

<u>Content</u>

1. To educate and inform two specific population groups -- the land user, and the local Soil and Water Conservation District Board Members.

2. To illustrate the land user and his local district working closely together to solve nonpoint source pollution problems.

3. To motivate for spontaneous voluntary response with an underlying message of possible regulatory requirement without the former.

4. To emphasize district involvement, flexible approaches and problem solving through the unique combination of the land user and the district cooperating and working toward a thoughtful successful solution.

5. To balance environmental and food needs, and to reinforce the value of present nonpoint pollution control practices as contrasted with practices which must be developed in the same successful style as other conservation practices have been implemented.

6. To include regional-national landscape and terrain footage with accompanying nonpoint source problem examples so that a nationwide audience can identify the importance of district involvement, cause and effect, and a vigilant awareness within a familiar area.

To carry out these objectives, over 7,000 feet of film was shot in the following locations to demonstrate the wide variety of nonpoint pollution problems and best management practices: Albuquerque, NM; Dane County, WI; Fort Wayne, IN (Black Creek Project); Jacksonville, FL; Mead, KS; Minot, ND; Portland, OR; Spokane, WA; Red Clay Project area in Wisconsin and Minnesota; Vancouver, WA; Washington, D.C. metropolitan area; Yuma, AZ.

While the film concentrates 10 of the 27½ minutes in the Red Clay Project area, the film is usable for a wide audience across the country. The sale of 50 copies of the film through our Film Library and rental of the 10 copies booked through the summer of 1978 are good indications of the response to the film.

The film has been copyrighted in NACD's name and submitted for awards by the producer.

In addition, some of the footage not used in <u>Nonpoint '83</u> has been used in another film produced for NACD to promote its Soil Stewardship Program.

We believe that the production of the film, videotape and film clips have accomplished several things:

A. These visual aids have helped develop an understanding that nationally nonpoint problems are varied and that the district approach can be effectively utilized to combat these problems.

B. These visual aids have filled a void in that no visual aids up to this time have addressed these nonpoint problems in terms of water quality.

C. Additional prestige and understanding of the value of demonstration projects has been added due to the visual impact and nationwide exposure.

D. These visual aids have helped to solidify NACD's position that the network of 3,000 local conservation districts working cooperatively with state and federal agencies are appropriate bodies to implement nonpoint water quality programs.

NACD is proud of the end products it contracted for because they will serve our country well. NACD is also proud that it delivered these services in essentially the time frame of the contract and within the budget allocated.

The original contract of $60,000 was amended on June 24, 1977 for $1,500 for increased cost and numbers of film prints and again on November 15, 1977 for $700 due to increased cost of the 25,000 flyer announcements.

MADIGAN BEACH FILM
by
Daniel Woods
Owner and Director
Farout Films Inc

During the 1977 installation of the Longard Tube system at Madigan Beach, Tony Wilhelm of Wilhelm Engineering took 16mm film footage of the installation process. Mr. Wilhelm then offered the use of the footage to the Red Clay Project.

The Project Executive Committee was interested in using the footage and after some discussion, decided to proceed with the production of a 10-15 minute film depicting the Madigan Beach story. The Project acquired the services of Dan Woods of Farout/ Woods/Basgen Films. The film was completed in late April 1978.

RESEARCH

RED CLAY SLOPE STABILITY FACTORS
LITTLE BALSAM CREEK DRAINAGE 92°15' W., 45°30' N,
DOUGLAS COUNTY, WISCONSIN

by

J. T. Mengel Jr. and B. E. Brown *

Prepared in Cooperation with:

Wisconsin Department of Transportation, District 8

Sponsored by:

United States Environmental Protection Agency
and
The Red Clay Project

Under terms of Grant Number G-005140-01

1979

* Professor, Department of Geosciences, University of Wisconsin-Superi
Professor, Geology Department, University of Wisconsin-Milwaukee

SUMMARY AND CONCLUSIONS

General Statement

Data collected in this investigation amplified knowledge of the mineralogical character and mechanical behavior of the red clay previously reported * and established a basis for recognizing slope stability type areas in the red clay plain which borders the northwestern side of Lake Superior.

The location of the Little Balsam Creek study area and the red clay area of Douglas County is shown in Figure 1.

The location of the 85 borings made to establish the stratigraphic succession are located on Figure 2. The log of each boring is given in Appendix 1.

Mineralogical and grain size determinations are summarized in Table 1 of Part II. Atterberg Limit determinations for these soils samples are also reported in Table 1.

Man's removal of the forest cover, modification of the natural drainage and other practices have promoted drying of a 5-7 foot thick surface zone throughout the red clay area. Slope instability results when: (1) decreased moisture causes fissure development in the brittle surface zone, which slides over plastic clay below if moisture accumulates in the fissures, and (2) increased slope angle and lack of toe support result from erosion of the base of a slope, allowing the surface to fail.

The changes which promote drying also affect the rate and quantity of runoff, thereby uncovering lateral and vertical erosive capacities as stream volumes and velocities increase. Even in localities where forest cover remains along portions of a stream course the entire natural relationship between streams and bank materials has been altered within the memory of those now living. The result has been an acceleration in the time rate of bank failure and an increase in its frequency throughout the red clay area. The topography will continue to evolve under the awesome power of natural processes but if humans use the land according to a plan which incorporates realistic agricultural and engineering practices, their rate of operation can be slowed and a new equilibrium established.

Recommendations

1. Channel deepening in any part of the red clay area be minimized through methods to retard upland runoff.

2. Slope toes be protected by vegetation or other means especially in reaches not now being actively eroded.

3. Efforts be made to maintain and improve vegetative cover and accumulation of a water-retaining mat of organic-rich materials which protect slopes from sheet erosion and maintain soil moisture at levels similar to those found at depths of about 10 feet or more.

* Mengel and Brown, 1976

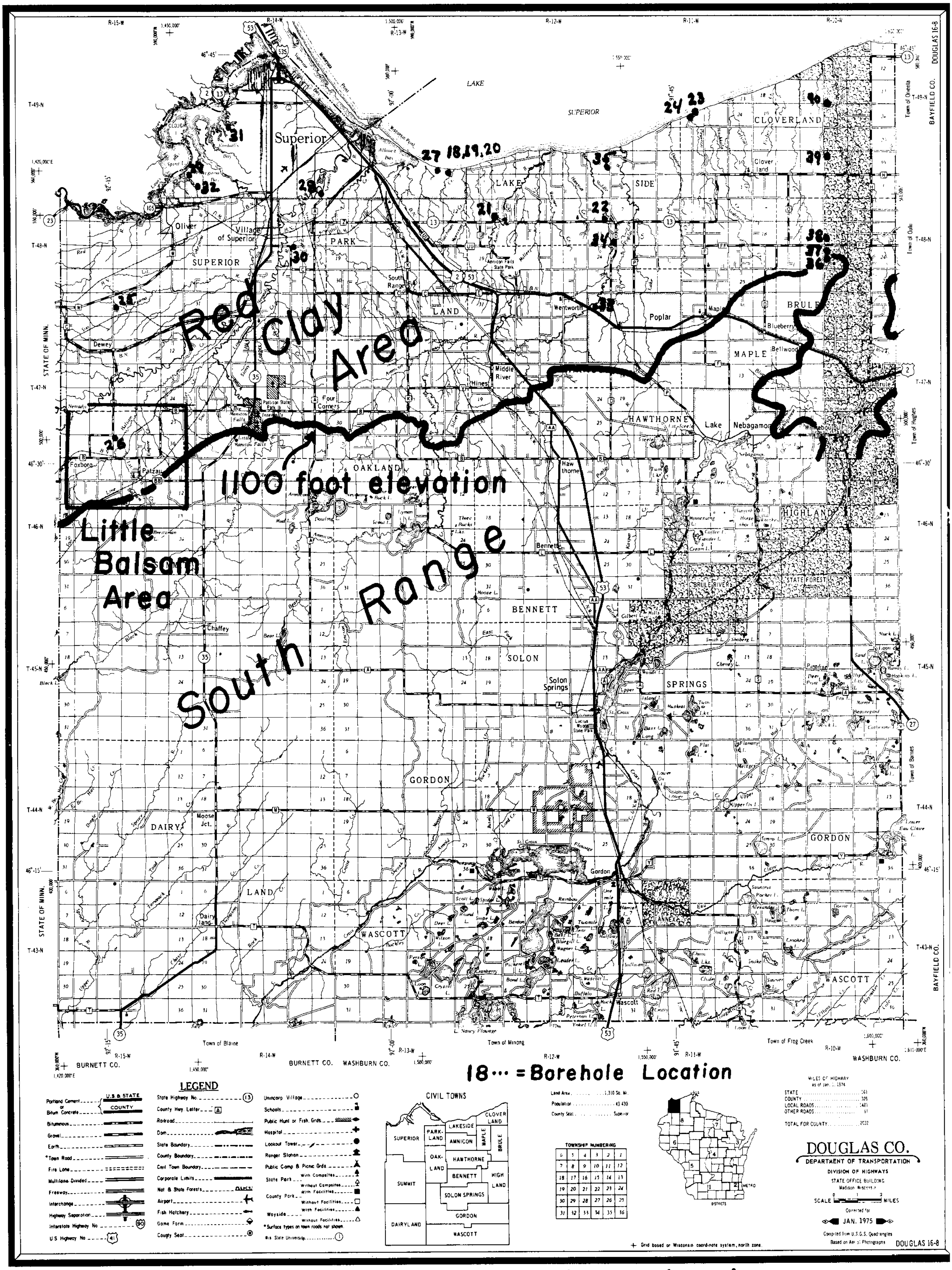


Figure I- Location of Area of Investigation

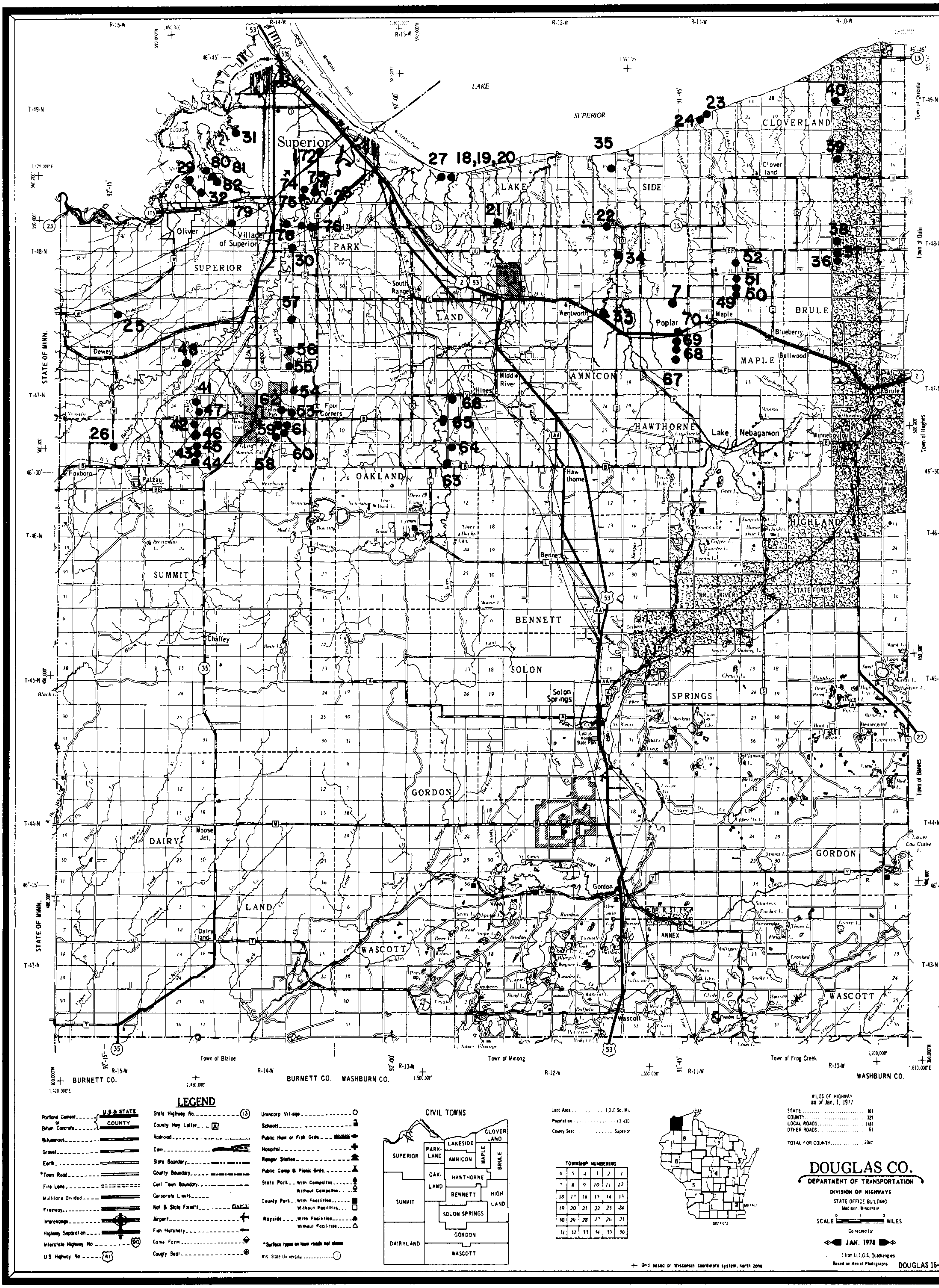


FIG. 2 - BOREHOLE LOCATIONS

Design of constructed slopes should include plans to:

1. Develop slope cover as soon as possible and not as the last detail of a construction schedule.

2. Bench to reduce land area involved; to permit the design of steeper slopes within critical height requirements and to control water run off down slope by interception and control on each bench.

Acknowledgements

It is a pleasure to recognize the central role in this investigation played by the Wisconsin Department of Transportation, District 8 and the personnel of its Materials Division, especially Mr. Emil Meitzner. The investigation would have been impossible without the wholehearted cooperation of Mr. Meitzner in all phases of the work.

The generous cooperation of the Wisconsin Geological and Natural History Survey and of the United States Soil Conservation Service is also gratefully acknowledged.

Part I

STRATIGRAPHIC SUCCESSION, SLOPE FAILURE PROCESSES AND SET-BACK SUGGESTIONS

Stratigraphic Succession

The Little Balsam Creek drainage was selected for investigation because it is representative of many of the geologic and engineering conditions in the Nemadji River watershed and other parts of the red clay plain.

In Douglas County, the altitude of the plain ranges from about 625 feet above mean sea level along Lake Superior to about 1100 feet along the South Range, a sand covered highland with a lava bed rock core which is the south boundary of the red clay area (Figure 1). The plain is underlain by several layers of glacially derived materials. These Quaternary age sediments are underlain by red sandstones or black basaltic lava flows of late Precambrian (Keweenawan) age.

The Quaternary age sediments accumulated at a time when the last continental glacier to cover the region was retreating but still filled the eastern end of the Lake Superior basin, impounding high level lakes in the west end (Fawand, 1969). The floor of these lakes, now the surface of the Plain, is being dissected by a drainage system which is still in a geologically youthful stage of evolution, and undergoing the kind of valley deepening and widening characteristic of such a stage.

In the Little Balsam Creek drainage south of the 1050 topographic contour the stratigraphic succession within about 30 feet of the upland surface is a clean fine to medium grained brown sand containing small amounts of gravel and rare boulders. A similar sand is present along the South Range across the county. The sands are above the level of strong lake action and exhibit a knob and kettle or channeled outwash topography which contracts sharply with the smooth upland surface of the red clay plain below an elevation of 1100 feet. In the Little Balsam area and elsewhere the sand grades laterally into the clay of the plain within a short distance.

North of the 1050 foot contour in the Little Balsam drainage the gently rolling upland surface of the plain is underlain by a red-brown clay layer which is up to about 25 feet thick. Beneath this layer the succession may include one of three other layers: (1) a second, older red clay; (2) brownish gray or grayish brown clays which show varves in some outcrops (SW 1/4-Sec. 34-T47N-R15W for example) (3) a fine to medium grained brown sand. The sands and varved clays may represent a time of temporary ice retreat between the times of ice advance recorded by the two red clays. The top of the older red clay layer shows markedly higher penetrometer strength than does the varved clay or basal part of the younger red clay.

Figure 3 shows the general extent of the portions of the red clay area underlain by each type of stratigraphic succession. Area I, including the coastal townships, much of Superior and the area south of the city, is underlain by two red clays having little other material between. Area II, the St. Louis River valley and the higher elevation adjacent to the South Range, is the portion of the red clay area wherein the upper and lower red clay layers are separated by considerable thicknesses of sand. Area III in-

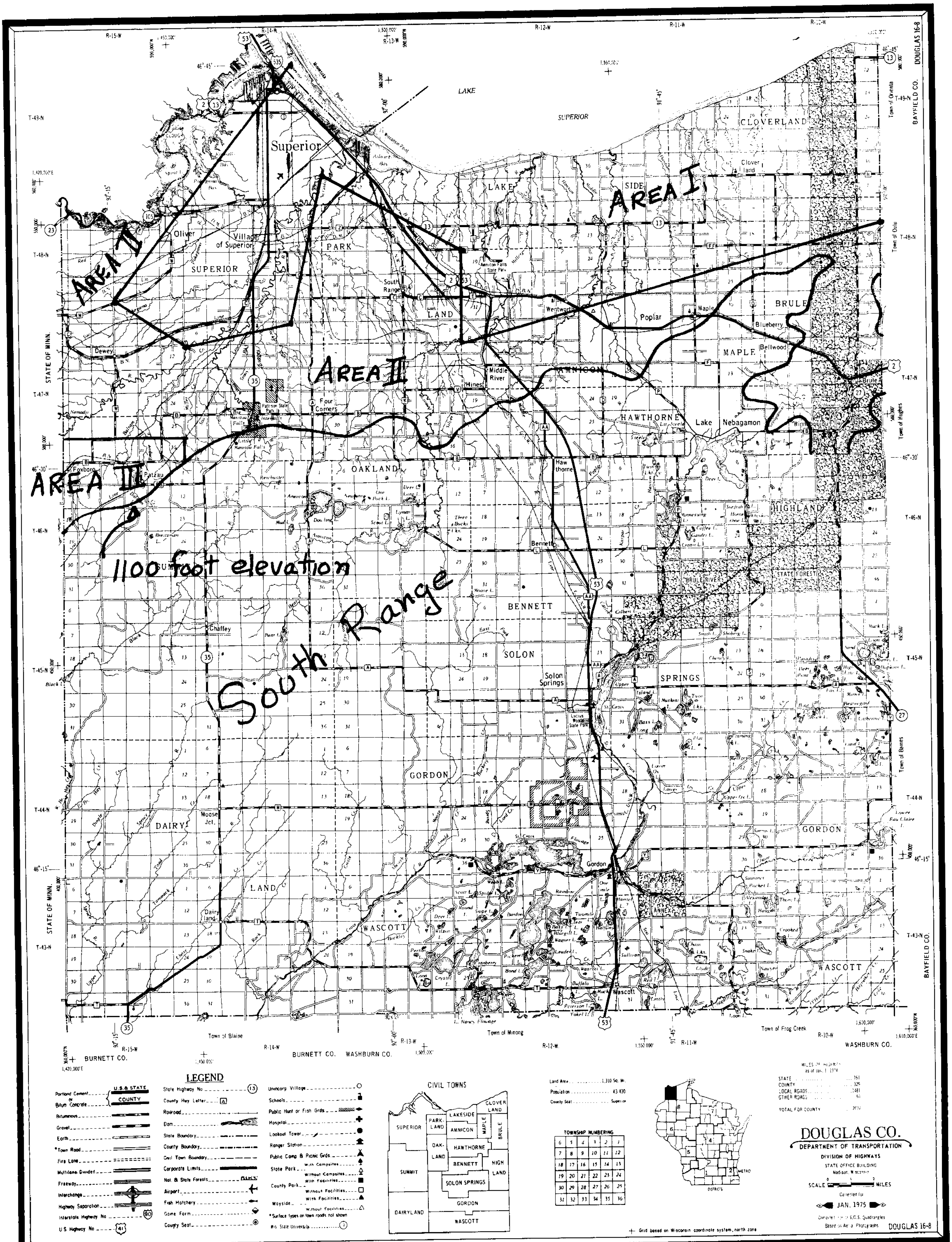


Figure 3 – Slope Stability Type Areas

cludes portions of the red clay area where the varved clays occur between the two red clays.

The stratigraphic succession determines the slope stability angle characteristics of each zone and influences the slope failure processes.

Slope Failure Processes

In the red clay district a variety of slopes are to be observed, ranging from those which are undergoing intense modifications to those which are approaching equilibrium. An equilibrium slope is the most nearly stable slope attainable under a given set of material and environmental circumstances. These slopes exhibit the lowest degree of inclination and are found under full natural plant cover in situations relatively protected from geologic and human disruption. In the red clay district such slopes have inclinations of about 6 to 10 degrees and typically are about 8 degrees. They occur along stream reaches protected by wide flood plains and along shore stretches well protected by beaches. At the other end of the stability spectrum are banks subject to current and/or wave attack along the coast line or on the outer side of meander curves where active erosion of the slope toe is occurring.

General slope conditions are easily identifiable on U.S. Geological Survey 7 1/2 minute topographic map quadrangles although the scale of the maps is not suitable for making precise slope angle determinations or for most types of construction site evaluation. Slope features such as degree of inclination, profile shape, and smoothness are indicators of the particular processes which are active. Lake Superior coast line slopes (Area I) locally exceed 60 degrees although typical slopes are no more than about 30 degrees. These slopes are highly irregular in detail and exhibit a closely spaced, irregular contour patterns on topographic maps. In Lakeside and Cloverland townships, and generally throughout Area I below about the 900 foot topographic contour the inclination of stream valley walls rarely exceeds 20 degrees and most slopes range between 12 and 17 degrees, measured rise over run, toe to crest (Figure 4). Most such slopes are convex in profile and exhibit regular topographic contour patterns. In Superior township detailed maps exhibit many slope irregularities, characteristic of slopes on which sliding is taking place.

In theory (Carson and Kirkby, 1972) slope flattening depends on the transporting capacity of the most active erosion agents and bears a functional relationship to bank inclination. The present investigation clearly indicated that on most natural clay slopes of less than 15 degrees creep is the principal erosion agent, and that on steeper slopes landsliding coupled with creep, mud flows, and occasional clay block slides or falls are the principal agents. Creep is particularly prominent everywhere because of the great depth (5-8 feet) of frost penetration results in heave of as much as several inches and because of moisture-related expansion and contraction of the montmorillonite-rich clay.

A gradational spectrum of land slide types may be observed. On slopes of about 15 to 18 degrees shallow translational slides - slides where materials move a thin sheet nearly parallel to the slope surface - may originate on any part of the slope. Such slides can be seen in Sections 8, 18 and 20, T48N, R12W. Translational movements affect only a layer of slope surface perhaps no greater than 4-6 feet deep. Within this layer, during dry weather, penetrometer-indicated bearing strength is usually over 4.5 tons per square foot (TSF) at the surface. Strength values decline to less than 0.5 TSF at depths of 2-4 feet and then rise to values near 1.0 TSF as depth increases. The surface layer is also penetrated by a mat of roots which further serve to give it cohesion. Such root systems of grass, shrubs, and canopy trees are limited to no more than about the uppermost 3-4 feet. This is the approximate depth to which moisture-related shrinkage cracks develop and permit water entry.

Sliding takes place along shear surfaces at the base of this coherent upper crust. It is promoted by crack development which in turn is related to modification of the surface vegetation. Natural jointing in the clay doubtless also contributes to the development of open fissures.

Slope failure can be initiated through undercutting of the slope toe by stream or lake action. First evidence of failure along the toe are high angle slips which allow blocks of material only a foot or so thick to slide down steep fractures into the water body. Failures migrate up slope where translatory and/or rotational sliding along shallow shear surfaces initiates one or several small, steep curving escarpments perhaps 2 to 4 feet high and 25 to 150 feet wide across the slope. Water entry into fissures opened by the sliding promotes movement as does water supplied from any granular horizons within the clay unit.

If very rapid toe erosion takes place, as it may on the outer side of some stream meanders and commonly does along the lake, rotational failure occurs along steeper, deeper and broader arcs and bank failure is potentially more destructive and dangerous. Once sliding takes place there is a tendency for very rapid removal of the badly cracked and remoulded toe materials and erosion rates are higher than they would be for undisturbed native clay. More or less rotational failures related to stream activity can be observed in NW-NW, Sec. 33, T48N, R12W and in Superior where U.S. Highways 2 and 53 cross Bear Creek; and lake related rotational slides can be seen along most of the coast. These latter are best observed from the air. In Superior township (Area II), failures are influenced by the presence of sand layers and probably also by artesian water conditions, or by water pressures within isolated sand bodies. A portion of County Trunk Highway A was permanently destroyed and the flow of the Nemadji River temporarily obstructed by such a slide which occurred during 1966 in SE Sec. 1, T48N, R14W. Similar serious rotational slippage also obstructed the Nemadji during 1973 in NE Sec. 21, T47N, R15W and a number of other such failures have taken place elsewhere in the Nemadji and in both of the Pokegama river drainages.

In Superior township (Area III) failure can, and frequently does take place on slopes of less than 15 degrees and some slopes with as gentle as 6 degrees inclination are still not in equilibrium. In all parts of the red clay district bank height does not necessarily determine sliding and disruptive failures can take place on slopes no more than 10 to 15 feet high. Accordingly all slopes should be viewed as potentially dangerous to construction works if their inclinations exceed suggested equilibrium angles. The likelihood of sliding increases with each added degree of inclination and probably no clay slopes in the district will long remain free from sliding if their inclination exceeds 15 degrees and a height of 10 feet. Since natural slopes in the red clay district evolve concurrently with a plant cover, and plants regulate moisture content, cracking, and soil removal, it is probable that constructed slopes higher than about 10 feet will fail at 15 degree inclinations unless measures are taken to protect them as quickly as possible. Vegetation on all slopes should be protected from serious disruption if natural equilibrium conditions are to be maintained. Thompson (1945) notes the value of willows in protecting stream banks from erosion along the Brule River, and such protection is amply evident along the Amnicon River as well. Since toe erosion is particularly apt to trigger bank failure willow growth should be encouraged where feasible.

Along the St. Louis River and elsewhere in Area II where sandy layers are major slope-forming materials, bank inclinations are typically steeper than 30 degrees and may locally be nearly vertical. Failure takes place in sandy materials throug individual grain movements at the surface, which are aided by strong winds in winter, spring, and fall, through very shallow translatory sliding, and through mass movements controlled by incipient high angle fracture surfaces. Rill development is also a factor in sand slope decay.

Construction Set-Back Suggestions

Construction set-back from bank crests can be estimated for each of the red clay regions of Douglas County using Chart I. This chart is based on average conditions and local exceptions may occur. Evaluation aid may be obtained from the Superior representative of the Wisconsin Geological and Natural History Survey, Department of Geosciences, University of Wisconsin-Superior, (715)392-8101, Extension 261.

Construction setback from bank crests can be estimated by making use of the basal angle of the slope (Figure 4). To determine the basal angle of a slope two points must be established: The crest, where the land first becomes relatively level and the toe, where the land becomes relatively level on the inner margin of a flood plain or at the edge of a stream. The two points must lie along a line whose bearing coincides with the steepest slope at the place where the determination is made. The steepest slope for any condition will be at right angles to the average compass trend direction of the slope. After the two points have been established, the vertical angle formed by a straight line joining the points is measured with an Abney Level or other instrument for determination of vertical angles, and the vertical bank height determined with the hand level. In heavily wooded areas or where slope conditions preclude establishing a line of sight,

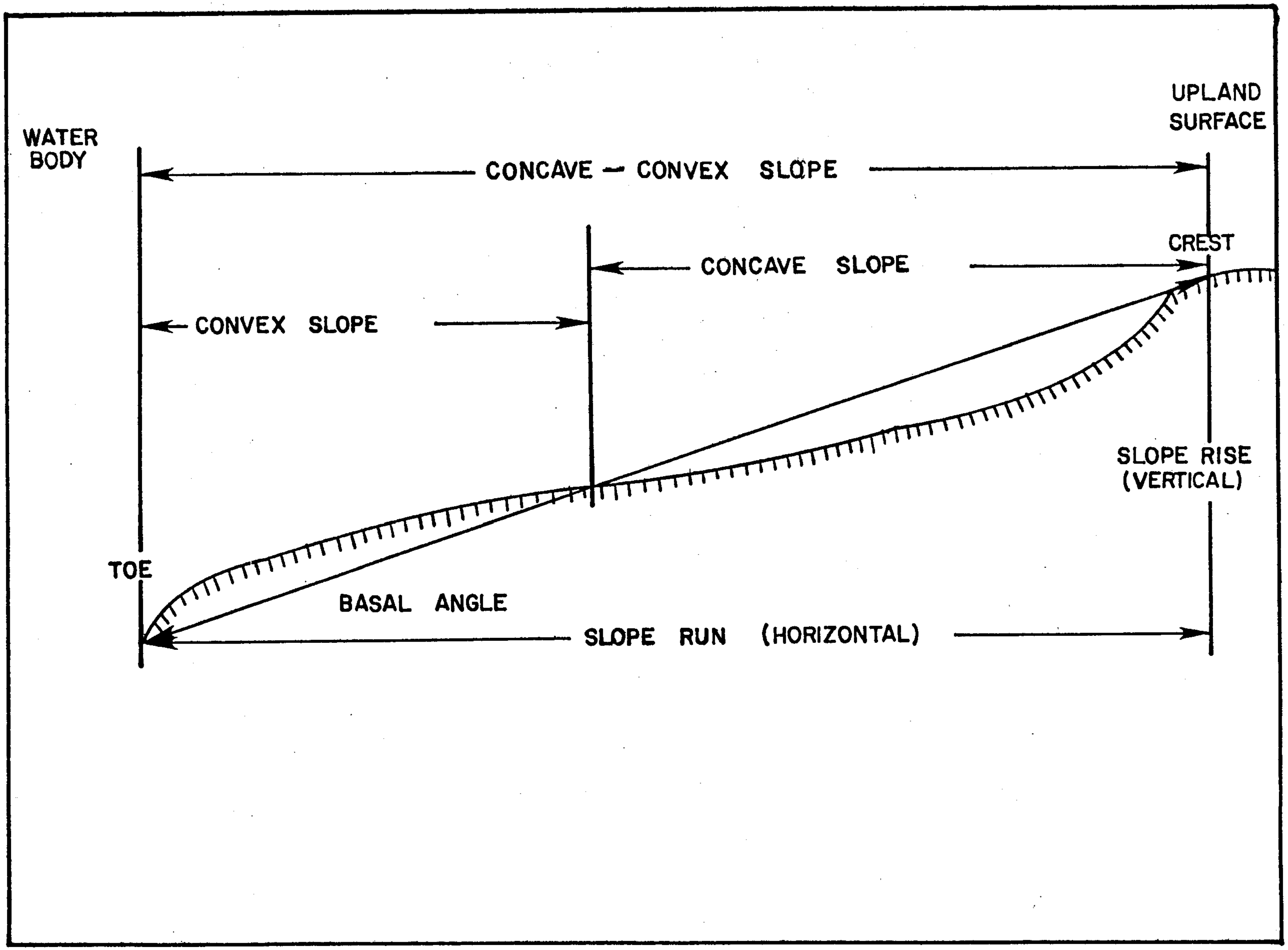
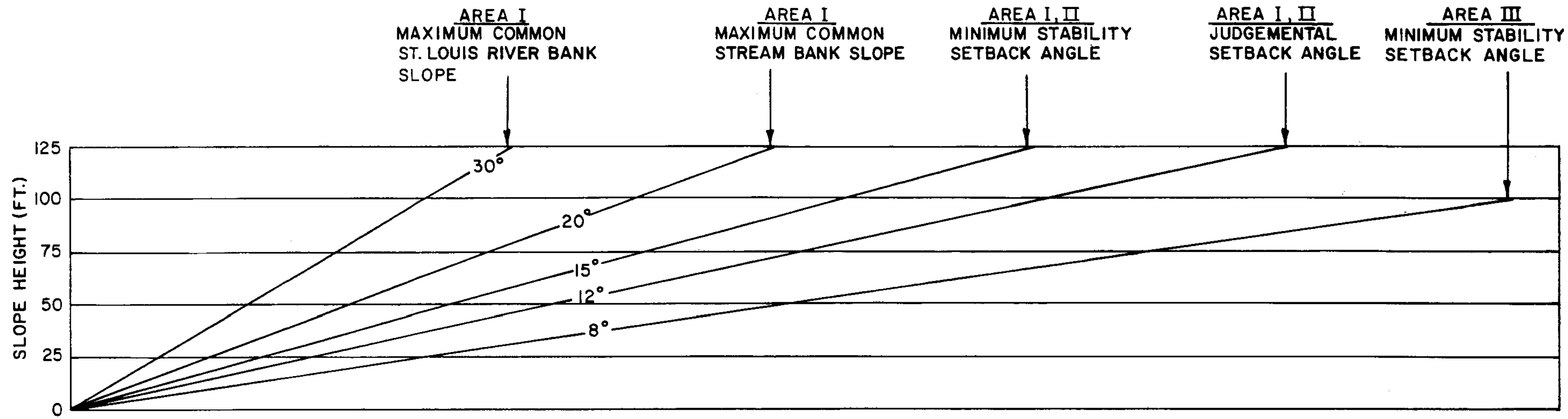

WATER BODY
UPLAND SURFACE
CONCAVE – CONVEX SLOPE
CONVEX SLOPE
CONCAVE SLOPE
CREST
SLOPE RISE (VERTICAL)
TOE
BASAL ANGLE
SLOPE RUN (HORIZONTAL)

CHART I – STREAM VALLEY SIDE SLOPES

SETBACK DISTANCES CORRESPONDING TO VARIOUS BANK HEIGHTS



SETBACK DISTANCE (FT.)

SCALE; 1"= 50' VERTICAL AND HORIZONTAL

ENTER CHART BY PLOTTING MEASURED BANK BASAL ANGLE AT THE ZERO POSITION, TRACE THIS ANGLE TO THE MEASURED BANK HEIGHT, MEASURE FOUNDATION SETBACK FROM BANK CREST BY FOLLOWING MEASURED BANK FREIGHT LINE TO THE RIGHT OF THE 15° BASAL ANGLE LINE (AREA I,II). IN AREA III AND ELSEWHERE, JUDGEMENT OF LOCAL CONDITIONS MAY INDICATE USE OF 12° OR 8° BASAL ANGLE CRITERION TO DETERMINE REASONABLE SETBACK.

the vertical height of the bank can be determined with the level in the usual manner and the slope distance with a tape. These quantites can be plotted on graph paper and the basal angle measured from the plot.

Enter Chart 1 with this angle and knowledge of the measured bank height to determine set-back distance for individual structures.

Slopes of 8 degrees are about as gentle as any which occur in the red clay region and have the highest degree of stability under natural weathering, erosion and vegetation conditions. Slopes with basal angles from 8 to 15 degrees look deceptively stable, but are subject to soil creep, and at angles close to 15 degrees may experience minor translatory slides. In this regard it is well to recognize that there may be no obvious downslope movement for years while materials are loosened and prepared for transport by the erosion agents and that then the net erosion of decades may take place in a short time.

Slopes having basal angles of more than 15 degrees are actively unstable and subject to periodic sliding. Adjustments are probable within the life of a typical structure, here arbitrarily defined as 60 years (three generations), and no major structure should be built here or major modification of vegetation be undertaken.

Resurvey of slope basal angles should be made as necessary to assess changing natural conditions or changes proposed by man. Ordinarily the basal angle will be nearly constant for long periods because of the slow rate of growth in valley width, but the angle should be re-determined at the time of property sale in order that the purchaser may understand existing conditions and future outlook.

BOREHOLE LOGS

4127 (1)

Depth	Thickness	
0-1	1	Sand, light brown.
1-2.5	1.5	Silt, brown.
2.5-11	8.5	Clay, stiff, silty.
11-14.5	3.5	Clay, stiff, with blue gray mottling and trace of weathered granite pebbles.
14.5-19.5	5	Clay, stiff with brown silt layers.

TD=19.5

4128 (2)

Depth	Thickness	
0-3	3	Sand, reddish brown.
3-4	1	Silt, reddish brown.
4-13	9	Clay, light brown, silty.
13-20	7	Clay, blue gray, silty.
20-24.5	4.5	Clay, gray.

TD=24.5

4129 (3)

Depth	Thickness	
0-1.5	1.5	Sand.
1.5-3.5	2	Silt, dark brown.
3.5-6	2.5	Silt, red brown.
6-15	9	Clay, red brown, silty, w/trace gravel.
15-24.5	9.5	Clay, reddish brown w/trace of silt.

TD=24.5

4130 (4)

Depth	Thickness	
0-1	1	Sand.
1-4.5	3.5	Silt, dark brown to black mottled.
4.5-6.5	2	Silt, reddish brown mottled.
6.5-10	3.5	Clay, yellowish brown, mottled, silty w/trace of gravel.
10-14	4	Clay, reddish brown, mottled, silty.
14-17	3	Silt, reddish brown w/sand and some clay.
17-20	3	Sand, reddish brown fine w/some silt; saturated w/water in hole at 20 feet.
20-29.5	9.5	Silt, dark brown, w/trace of gravel and some sand.

TD=29.5

BOREHOLE LOGS

4131 (5)

Depth	Thickness	
0-2	2	Sand.
2-4	2	Silt, reddish brown with some clay layers.
4-14.5	10.5	Silt, reddish brown with a little fine sand.
14.5-23	8.5	Silt, reddish brown with a little sand and gravel and dense silt and sand layers.
23-24.5	1.5	Sand, fine with some silt.

TD=24.5

4132 (6)

Depth	Thickness	
0-6	6	Sand.
6-21	15	Sand, fine, with some pea size gravel.
21-23.5	2.5	Sand, fine, with some gravel layers.
23.5-29.5	6	Sand, fine.

TD=29.5

4133 (7)

Depth	Thickness	
0-1	1	Sand, fine.
1-10	9	Sand, reddish brown.
10-15	5	Sand, medium coarse.
15-20	5	Sand, silty w/trace of gravel.
20-29.5	9.5	Glacial fill, sandy with some silt and pea size gravel.

TD=29.5

4134 (8)

Depth	Thickness	
0-11.5	11.5	Sand, silty with some pea size gravel.
11.5-20	8.5	Sand, with fine sand and silt layers.
20-22.5	2.5	Sand, fine to medium grained.
22.5-29.5	7.0	Silt, with fine sand.

TD=29.5

BOREHOLE LOGS

4135 (9)

Depth	Thickness	
0-9	9	Silt with some sand and gravel.
9-24.5	15.5	Sand with silt layers.

TD=24.5

4136 (10)

Depth	Thickness	
0-5	5	Sand, fine with some silt.
5-19	14	Silt with some fine sand and gravel layer. at 11-12 feet and becoming densely layered at 17 feet.
19-24.5	6.5	Silt and fine sand with silt layers.

TD=24.5

4137 (11)

Depth	Thickness	
0-10.5	10.5	Silt with some clay.
10.5-24.5	14	Sand, fine, densely layered.

TD=24.5

4236 (12)

Depth	Thickness	
0-1	1	Top soil, black, silty.
1-28	27	Clay, brown, very stiff, with a little silt and layers of silt at 8-9, and 15-16.
28-68	40	Clay, medium brown with a little silt and sand.
68-73	5	Silt, gray, firm, with some sand and gravel.
73-80.5	7.5	Sand, brown, fine to medium grained, very dense.

TD=80.5

BOREHOLE LOGS

4273 (13)

Depth	Thickness	
0-1	1	Sand, road bed on dark brown top soil.
1-23	22	Clay, red, w/little silt, sand, trace of pea size gravel.
23-24.5	1.5	Clay, interlayered red and gray.
24.5-34.5	10	Clay, olive gray, stiff, silty with trace of sand.
TD=34.5		

4274 (14)

Depth	Thickness	
0-1	1	Sand, gravel road bed on dark brown top soil.
1-22	21	Clay, red brown, w/little silt, sand, trace of pea size gravel.
22-28.5	6.5	Clay, red brown, interlayered with clay, gray to olive brown.
28.5-34.5	6	Clay, dark gray to olive brown or olive yellow, moderately silty with trace of sand.
TD=34.5		

4275 (15)

Depth	Thickness	
0-1	1	Sand, gravel of read bed on brown top soil.
1-29.5	28.5	Clay, red brown, stiff, with some silt, sand and pea size gravel.
29.5-34.5	5	Clay, gray to olive gray, mottled, silty.
TD=34.5		

4276 (16)

Depth	Thickness	
0-2	2	Top soil, clay, red brown silty w/trace of sand.
2-21	19	Clay, yellowish red, very stiff, silty with trace of sand and gravel.
21-25	4	Clay, silty, gray brown.
25-27	2	Clay, light brownish gray, moderately silty.
27-29.5	2.5	Clay, gray silty.
TD=29.5		

BOREHOLE LOGS

4277 (17)

Depth	Thickness	
0-1.5	1.5	Clay, reddish brown, silty.
1.5-3.5	2	Layers of clay, gray, silty and clay red brown silty.
3.5-12	8.5	Clay, gray brown silty w/some fine sand.
12-13	1	Clay, red brown, soft, silty.
13-16.5	3.5	Clay, dark gray, soft, silty.
16.5-19.5	3	Clay, dark red and gray, soft, silty w/some fine sand.

TD=19.5

4278 (18)

Depth	Thickness	
0-1	1	Sand and gravel of road bed.
1-26	25	Clay, dark reddish brown, stiff, with little silt, sand, pea size gravel; boulder at 10.5.
26-27.5	1.5	Clay, reddish brown, sandy.
27.5-29.5	2	Sand, brown, fine w/a few pieces of pea size gravel.

TD=29.5

4279 (19)

Depth	Thickness	
0-24.5	24.5	Clay, reddish brown, with some silt, sand and pea size gravel.

TD=24.5

4280 (20)

Depth	Thickness	
0-11.5	11.5	Clay, reddish brown, w/some silt, sand and gravel.
11.5-23.5	12	Clay, reddish brown interlayered w/gray clay w/some silt, sand, and gravel.
23.5-39.5	16	Silt and fine sand, reddish brown, with some clay, saturated below 34 feet.

TD=39.5

BOREHOLE LOGS

4281 (21)

Depth	Thickness	
0-1	1	Top soil .
1-9.5	8.5	Clay, dark red, stiff, moderately silty to sandy .

TD=9.5

4282 (22)

Depth	Thickness	
0-1	1	Sand and gravel of road bed .
1-9.5	8.5	Clay, dark red, stiff, moderately silty to sandy w/few white carbonate concretions .

TD=9.5

4283 (23)

Depth	Thickness	
0-4.5	4.5	Sandy beach material with some pea size gravel .
4.5-12.5	8	Sand, brown, fine to silty .

TD=12.5

4284 (24)

Depth	Thickness	
0-24.5	24.5	Clay, dark red, slightly silty to silty with few pebbles of pea size gravel .

TD=24.5

4586 (25)

Depth	Thickness	
0-39.5	39.5	Clay, reddish brown, w/some silt and sand and few pieces of pea-size gravel. Stiff near surface.

TD=39.5

4587 (26)

Depth	Thickness	
0-34.5	34.5	Clay, reddish brown with some silt and sand and few pieces of pea-size gravel. Stiff near surface.

TD=34.5

BOREHOLE LOGS

4588 (27)

Depth	Thickness	
0-29.5	29.5	Clay, reddish brown with some silt and sand and a few pieces of pea-size gravel. Boulder or large cobble at 14 feet. Stiff near surface.
TD=29.5		

4589 (28)

Depth	Thickness	
0-24	24	Clay, reddish brown, with some silt and sand and a few pieces of pea-size gravel. Stiff near surface.
24-39.5	15.5	Sand, brown, fine medium grained, clean, with several 1 to 1.5 ft. thick layers of loamy sand interlayered.
TD=39.5		

4590 (29)

Depth	Thickness	
0-10.5	10.5	Clay, reddish brown, with some silt and sand and a few pieces of pea-size gravel. Stiff.
10.5-19.5	9	Sand, brown, medium grained with some pea-size and larger pieces of gravel.
TD=19.5		

4591 (30)

Depth	Thickness	
0-24.5	24.5	Clay, reddish brown, with some silt and sand and a few pieces of pea-size gravel. Stiff near surface.
24.5-34.5	10	Clay, red brown, with some silt and sand and a few pieces of pea-size gravel. Stiff.
TD=34.5		

4604 (31)

Depth	Thickness	
0-14.5	14.5	Clay, dark red, stiff, w/trace silt, sand and pea-size gravel.
14.5	-	Sand, brown, medium to fine grained, slightly moist.
TD=14.5		

BOREHOLE LOGS

4605 (32)

Depth	Thickness	
0-13.5	13.5	Clay dark red, stiff with trace silt, sand and pea-size gravel.
13.5-24.5	11	Sand, brown, medium grained w/pea to small gravel in deeper layers.
TD=24.5		

4606 (33)

Depth	Thickness	
0-16.5	16.5	Clay, dark reddish brown, very stiff, with trace sand, silt, calcareous concretions.
16.5	-	Sand, red brown w/pea-size to fine gravel, including sandstone pebbles.
TD=16.5		

4607 (34)

Depth	Thickness	
0-11	11	Clay, dark reddish brown, stiff, with some silt, sand and pea-size gravel.
11-19.5	8.5	Clay, dark reddish, stiff with much sand and pea-size gravel.
TD=19.5		

4608 (35)

Depth	Thickness	
0-24.5	24.5	Clay, dark reddish brown, stiff with some silt, sand and pea-sized gravel.
TD=24.5		

4609 (36)

Depth	Thickness	
0-3	3	Fill and top soil.
3-5.5	2.5	Sand, yellowish brown, medium, clean with a little clay.
5.5-12.5	7	Sand, red brown, medium w/a little gravel and enough clay to mould.
12.5-13.5	1	Basalt.
TD=13.5		

BOREHOLE LOGS

4610 (37)

Depth	Thickness	
0-1	1	Fill.
1-16.5	15.5	Clay, red brown with large amount of silt, sand and some gravel.
16.5-24.5	8	Sandstone, yellow brown, fine, clean.

TD=24.5

4611 (38)

Depth	Thickness	
0-22	22	Clay, dark reddish brown, stiff, with a little silt, sand and pea-size gravel.
22-24.5	2.5	Clay, silt, sand, red brown.

TD=24.5

4612 (39)

Depth	Thickness	
0-24.5	24.5	Clay, dark reddish brown, stiff, with some silt, sand, and pea-size gravel.

TD=24.5

4613 (40)

Depth	Thickness	
0-24.5	24.5	Clay, dark reddish brown, stiff, with some silt, sand, and pea-sized gravel.

TD=24.5

BOREHOLE LOGS

4688 (41)

Depth	Thickness	
0-5.5	5.5	Clay, red brown, stiff w/some silt, sand and pea gravel.
5.5-7.0	1.5	Clay, red brown, very sandy.
7.0-9.5	2.5	Gravel, brown sandy.
9.5-11.5	2.0	Clay, red brown, with thin gray layers.
11.5-13.5	2.0	Sand, red brown, clayey.
13.5-14.5	1.0	Clay, red brown, very stiff, w/a little sand.
14.5-19.5	5.0	Sand, red brown, medium grained with a trace of pea gravel and some clay.
19.5-24.5		Clay, red brown, sandy.

TD=24.5

4689 (42)

Depth	Thickness	
0-19.5	19.5	Clay, red brown, slightly silty, sandy, trace pea gravel. occasional thin gray silty layers.
19.5-29.5	10.0	Clay, dark gray, slightly silty with a trace of fine sand.

TD=29.5

4690 (43)

Depth	Thickness	
0-9.5	9.5	Clay, dark red brown, stiff, slightly silty, sandy, trace of pea gravel.

TD=9.5

4691 (44)

Depth	Thickness	
0-3.0	3.0	Road fill
3-24.5	21.5	Sand, yellow brown grading to red brown, medium grained with trace of pea gravel and clay.

TD=24.5

BOREHOLE LOGS

4941 (45)

Depth	Thickness	
0-5.5	5.5	Clay, red brown, stiff with much silt, sand, some pea gravel.
5.5-7.5	2.0	Clay, brown, with large amount silt and fine to medium grained sand.
7.5-34.5	27.0	Sand, brown, fine to medium grained with variable amounts of clay and fine gravel.

TD=34.5

4942 (46)

Depth	Thickness	
0-4.5	4.5	Sand, red brown, fine to medium grained with large but variable amounts of clay and pea gravel.
4.5-6.0	1.5	Clay, red brown, stiff, with a little silt, sand, and rare pea gravel.
6.0-9.5	3.5	Clay, red brown, slight amount of silt, sand, pea gravel.
9.5-23.0	13.5	Clay, gray brown to brown gray, stiff with a little silt, sand, and gravel to one inch diameter.
23.0-29.5	6.5	Clay, brown, with small amount silt and fine sand.

TD=29.5

4943 (47)

Depth	Thickness	
0-2.0	2.0	Road fill
2.0-3.0	1.0	Clay, black, organic rich, very finely sandy.
3.0-9.5	6.5	Clay, red brown, stiff, a little silt, sand, pea gravel.
9.5-14.5	5.0	Clay, red brown, stiffer and with a little more pea gravel.
14.5-19.5	5.0	Clay, red brown, more plastic, a little less pea gravel.

TD=29.5

BOREHOLE LOGS

4944 (48)

Depth	Thickness	
0-1.0	1.0	Road fill
1.0-19.5	18.5	Clay, brown, very stiff, slightly silty, sandy, trace of pea gravel.

TD=19.5

4945 (49)

Depth	Thickness	
0-6.0	6.0	Sand, light brown, medium grained with trace of pea gravel.
6.0-7.5	1.5	Silt, brown, w/some very fine sand and clay.
7.5-10.0	2.5	Sand, brown, fine to medium grained, very high clay content.
10.0-14.5	4.5	Clay, red brown, stiff, with a little silt, fine sand, pea gravel.
14.5-19.5	5.0	Clay, red brown, very stiff, with some thin gray layers. "hard pan".

TD=19.5

4946 (50)

Depth	Thickness	
0-1.0	1.0	Road fill
1.0-1.5	0.5	Silt, gray brown, sandy
1.5-9.5	8.0	Clay, red brown, stiff, with a little silt, sand, pea gravel.
9.5-13.5	4.0	Clay, brown, stiff, with a little silt, sand, pea gravel. Frictional refusal at 13.5.

TD=13.5

4947 (51)

Depth	Thickness	
0-.5	0.5	Road fill
.5-1.5	1.0	Top soil, black, sandy.
1.5-2.0	0.5	Silt, gray brown
2.0-4.5	2.5	Clay, red brown, stiff with a little silt, sand, pea gravel.
4.5-7.5	3.0	Clay, red brown, stiff with much sand, pea gravel.
7.5-14.5	7.0	Clay, red brown, with a little silt, sand, pea gravel.

TD=14.5

BOREHOLE LOGS

4948 (52)

Depth	Thickness	
0-3.0	3.0	Top soil, brown to black
3.0-3.5	0.5	Silt, brown to gray
3.5-19.5	16.0	Clay, red brown, stiff with a little silt, sand, pea gravel. A very thin sand seam with water at 14.5.

TD=19.5

4949 (53)

Depth	Thickness	
0-3.5	3.5	Sand, yellow brown, medium grained with some pea gravel.
3.5-5.5	2.0	Sand, red brown fine to medium grained, no pea gravel.
5.5-12.0	6.5	Sand, red brown, fine grained to silt, considerable clay.
12.0-18.0	6.0	Clay, dark red brown, stiff with a little silt, sand, pea gravel.
18.0-19.5	1.5	Clay, dark gray, stiff with a little silt, sand, pea gravel.
19.5-24.5	5.0	Clay, dark red brown, with a little silt, sand, pea gravel.

TD=24.5

4950 (54)

Depth	Thickness	
0-4.0	4.0	Clay, red brown very stiff, with a little silt, sand, pea gravel.
4.0-15.0	11.0	Clay, yellow brown, trace of silt.
15.0-29.5	14.5	Clay, reddish brown, with trace silt and sand.

TD=29.5

4951 (55)

Depth	Thickness	
0-4.0	4.0	Clay, red brown, stiff with a little silt, sand, pea gravel.
4.0-12.5	8.5	Clay, red brown, very stiff with a little silt, sand, pea gravel.
12.5		Refusal, few chips of dark gray basalt bed rock.

TD=12.5

BOREHOLE LOGS

4952 (56)

Depth	Thickness	
0-1.0	1.0	Road fill
1.0-24.5	23.5	Clay, red brown, stiff, with a little silt, sand, pea gravel.

TD=24.5

4953 (57)

Depth	Thickness	
0-5.5	5.5	Clay, red brown, stiff, with a little silt, sand, pea gravel.
5.5-9.5	4.0	Clay, grayish red, stiff, silty.
9.5-13.5	4.0	Clay, red brown, stiff with a little silt, sand, pea gravel.
13.5-19.5	6.0	Clay, red brown, very stiff, with much pea gravel.

TD=19.5

4954 (58)

Depth	Thickness	
0-2.0	2.0	Sand, brown, medium grain with a little pea gravel.
2.0-6.5	4.5	Clay, red brown, with much silt, sand, pea gravel.
6.5-32.5	26.0	Sand, brown, medium to coarse grained, with variable but small amounts of clay.

TD=32.5

4955 (59)

Depth	Thickness	
0-1.0	1.0	Road fill
1-8.0	7.0	Sand, yellow brown, medium to coarse grained.
8.0-14.5	6.5	Clay, red brown, stiff, with a little silt, sand, pea gravel.

TD=14.5

4956 (60)

Depth	Thickness	
0-29.5	29.5	Sand, brown, medium to coarse grained, with a little clay and pea gravel.

TD=29.5

BOREHOLE LOGS

4966 (61)

Depth	Thickness	
0-4.5	4.5	Sand, yellow brown, medium to coarse grained with a little fine gravel.
4.5-9.5	5.0	Clay, dark reddish brown, stiff, with a little silt, sand, pea gravel.

TD=9.5

4967 (62)

Depth	Thickness	
0-1.0	1.0	Road fill
1.0-6.5	5.5	Clay, red brown, stiff, with a little silt, sand, pea gravel.
6.5-14.0	7.5	Clay, mottled olive gray brown with a little silt, sand, pea gravel.
14.0-18.00	4.0	Clay, red brown, stiff, with a little silt, sand, pea gravel.
18.0-21.5	3.5	Clay, reddish dark brown, silty.
21.5-24.0	2.5	Clay, grayish red brown.
24.0-26.0	2.0	Sand, dark reddish brown, medium grained with considerable clay.

TD=26.0

4968(63)

Depth	Thickness	
0-29.5	29.5	Sand, yellow brown with a little pea gravel, rare crystalline rock boulders in sand pit near by.

TD=29.5

4969(64)

Depth	Thickness	
0-24.5	24.5	Sand, yellow brown, medium grained. Upper 2.5 feet with some cobbles and boulders.

TD=24.5

4970(65)

Depth	Thickness	
0-9.5	9.5	Sand, yellow brown, medium grained tending to be more silty with depth.
9.5-13.0	3.5	Clay, reddish brown, stiff, with a little silt, sand, pea gravel.
13.0-17.0	4.0	Clay reddish brown, stiff, very sandy with many small pebbles.
17.0-19.5	2.5	Sand, reddish brown, very clayey.

TD=19.5

BOREHOLE LOGS

4971 (66)

Depth	Thickness	
0-11.0	11.0	Sand, yellow brown, medium to coarse grained, with small amount of fine gravel gradually becoming finer grained with depth.
11-12.5	1.5	Silt, dark red brown.
12.5-29.5	17.0	Clay, dark red brown, soupy, with a little silt, sand, pea gravel.
TD=29.5		

4972 (67)

Depth	Thickness	
0-9.5	9.5	Sand, red brown, medium grained, clayey with a little pea gravel.
9.5		Refusal - probably basalt bed rock
TD=9.5		

4973 (68)

Depth	Thickness	
0-16.5	16.5	Sand, red brown, medium to coarse grained, with a little fine gravel and enough clay to mold in hand.
16.5		Refusal - probably basalt bed rock.
TD=16.5		

4974 (69)

Depth	Thickness	
0-13.0	13.0	Sand, dark reddish brown, medium grained with a little pea and fine gravel and enough clay to mold in hand.
13.0-22.5	9.5	Sand, dark brownish gray, clayey and pebbly with rare boulders.
22.5		Refusal - weathered and fractured basalt.
TD=22.5		

4975 (70)

Depth	Thickness	
0-3.5	3.5	Sand, yellow brown, medium grained with a few stiff yellow brown clay layers.
3.5-12.5	9.0	Sand, red brown, clayey with a little pea and fine gravel.
12.5		Refusal - possibly a boulder in fine gravel.
TD=12.5		

BOREHOLE LOGS

4976 (71)

Depth	Thickness	
0-2.0	2.0	Road fill over thin brown to black top soil.
2.0-19.5	17.5	Clay, red brown, stiff with a little silt, sand, pea gravel.

TD=19.5

5077 (72)

Depth	Thickness	
0-1.5	1.5	Road fill over black organic rich top soil.
1.5-34.5	33.0	Clay, red brown, stiff, with a little silt, sand, pea gravel, gradually declines in stiffness with depth.

TD=34.5

5078 (73)

Depth	Thickness	
0-29.5	29.5	Clay, red brown, stiff, with a little silt, sand, pea gravel. Slightly more pea gravel 20-24.5.

TD=29.5

5090 (74)

Depth	Thickness	
0-21.5	21.5	Clay, red brown, stiff, with a little silt, sand, pea gravel. Slightly more pea gravel 15-20.
21.5-24.5	3.0	Clay, red brown, with a little silt, sand, pea gravel and a few stiff yellow brown sandy layers.
24.5-27.5	3.0	Clay, red brown, very stiff, more silt, sand, pea gravel.
27.5-29.0	1.5	Sand, brown, fine to medium grained, saturated.
29.0-34.5	5.5	Clay, red brown, stiff, with a little pea and fine gravel and a few thin brown, medium grained sand layers.

TD=34.5

5091 (75)

Depth	Thickness	
0-5.5	5.5	Clay, red brown, stiff, with a little silt, sand, pea gravel and a few very thin grayish silt layers.
5.5-7.5	2.0	Sand, brown, silty toward top grading downward to coarse grained with pea gravel, saturated.
7.5-24.5	17.0	Clay, red brown, stiff, with a little pea and fine gravel.

TD=24.5

BOREHOLE LOGS

5092 (76)

Depth	Thickness	
0-1.0	1.0	Road fill
1.0-29.5	28.5	Clay, red brown, stiff becoming gummy with depth, with a little silt, sand, pea gravel.

TD=29.5

5093 (77)

Depth	Thickness	
0-1.0	1.0	Road fill
1.0-8.0	7.0	Clay, red brown, stiff, a little silt, sand, pea gravel.
8.0-24.5	16.5	Clay, brownish red, stiff, with variable but generally more silt, sand and pea gravel than above.

TD=24.5

5094 (78)

Depth	Thickness	
0-1.0	1.0	Road fill
1.0-24.5	23.5	Clay, red brown, stiff, with a little silt, sand, pea gravel. Several high angle joint sets evident in ditch exposures.

TD=24.5

5100 (79)

Depth	Thickness	
0-1.5	1.5	Road fill
1.5-2.5	1.0	Clay, dark gray w/marsh vegetation.
2.5-19.5	17.0	Clay, red brown, stiff w/trace silt, pea gravel.
19.5-34.5	15.0	Clay, red brown, no strength ("slop").

TD=34.5

5101 (80)

Depth	Thickness	
0-0.5	0.5	Black forest soil.
0.5-10.0	9.5	Clay, red brown, very stiff w/trace silt, sand, pea gravel.
10.0-14.5	4.5	Sand, brown, medium to coarse with a little fine gravel. Nearly dry.

TD=14.5

BOREHOLE LOGS

5102 (81)

Depth	Thickness	
0-13.0	13.0	Clay, red brown, very stiff, with trace silt, sand, pea gravel and a few very thin grayish clay layers in the interval.
13.0-21.5	8.5	Sand, brown, medium to coarse with some pea gravel. Nearly dry.

TD=21.5

5103 (83)

Depth	Thickness	
0-8.5	8.5	Clay, creamy red brown, stiff, with trace silt, sand, pea gravel.
8.5-24.5	16.0	Clay, dark red brown, with trace silt, sand, pea gravel, strength higher than above.

TD=24.5

5216 (83)

Depth	Thickness	
0-4.5	4.5	Clay, brown, silty, with some fine gravel.
4.5-8.0	3.5	Silt, light brown, w/fine sand and enough clay to be molded.
8-9.5	1.5	Clay, red brown, with a trace silt, sand, pea gravel.
9.5-11.5	2.0	Silt, dark gray, very fine, won't roll into 1/8" threads. Too difficult to drill.

TD=11.5

5217 (84)

Depth	Thickness	
0-12.5	12.5	Clay, red brown, stiff with a little silt, sand, pea gravel and calcareous concretions.
12.5-14.5	2.0	Sand, brown, fine, silty at top becoming medium grained with fine gravel. Nearly dry.

TD=14.5

BOREHOLE LOGS

5218 (85)

Depth	Thickness	
0-1.0	1.0	Road fill
1.0-2.0	1.0	Organic rich clay
2.0-4.5	2.5	Clay, red brown, stiff, with trace silt, sand, pea gravel.
4.5-9.5	5.0	Clay, brown, stiff with trace silt, sand, fine gravel. A few very thin silty clays.
9.5-24.5	15.0	Clay, light red brown, stiff with trace silt, sand, fine gravel.

TD=24.5

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PART II

MINERALOGY AND PARTICLE SIZE DISTRIBUTION IN THE RED CLAY

PARTICLE SIZE DISTRIBUTION IN THE RED CLAY

DISPERSION AND SEPARATION METHODS

The particle size distribution data (as well as mineralogical and mechanical data) is summarized in Table 1. Samples from holes 4236 to 4284 were the first group to be analyzed and are dealt with in detail in the final report on the Little Balsam Creek area (Mengel and Brown, 1976). Samples from drill holes 4586 to 4613 were analyzed by David C. Meyers and his report is found in an M.S. thesis "The Mineralogy of the Red Clay and its Relation to Slope Stability in Douglas County, Wisconsin" (1977). Samples from drill holes 4689 to 5103 make up a group not reported on previously but cover a representative range of Red Clay locations. The locations of the drill holes referred to above can be found on the index map, Part I.

Particle size distribution measurement requires dispersion and separation. Dispersion methods used on the above samples can be outlined as follows:

1) Sample groups 4236-4284 and 4689-5103.
   a) Removal of iron oxide colloidal pigment by citrate-dithionite method of Aguilera and Jackson (1953),
   b) Dispersion of aggregate using sodium hexametaphosphate dispersant (0.5%).
2) Sample group 4586-4613.
   a) Removal of soluble carbonates using pH 5.0 acetic acid sodium acetate buffer solution,
   b) Dispersion with 0.01N sodium oxalate solution.

The methods used above will result in some final differences in results particularly as regards carbonate contents, since the pH 5.0 treatment is designed to remove carbonate material.

The separation methods used in the sample groups can be outlined as follows:

1) Sample group 4236-4284. Sand (greater than 44 microns) is separated using wet sieving procedures, silt fractions were separated at 20 microns and at 5 microns by gravity settling procedures, and clay fractions were separated at 2 microns and 0.2 microns by centrifuge washing techniques. The general methods used here can be found in detail in Jackson (1956, p. 101). An independent check on particle size results for the clay fractions were made using the pipette method outlined by Volk (p. 37, 1974).

2) Sample group 4586-4613. Sand (greater than 44 microns) was separated by wet sieving, silt (44-2 microns), coarse clay (2-0.2 microns), and fine clay (less than 0.2 microns) were separated by centrifuge techniques, Passaro (1961, p. 68). Total silt and clay were determined by the pipette withdrawal method to validate the centrifuge data. As noted, samples in this group were done by D. Meyer.

3) Sample group 4689-5103. Sand (greater than 44 microns) was separated by wet sieving, and centrifuge techniques were used to separate silts (44-2 microns), coarse clay (2-0.2 microns) and fine clays (less than 0.2 microns),

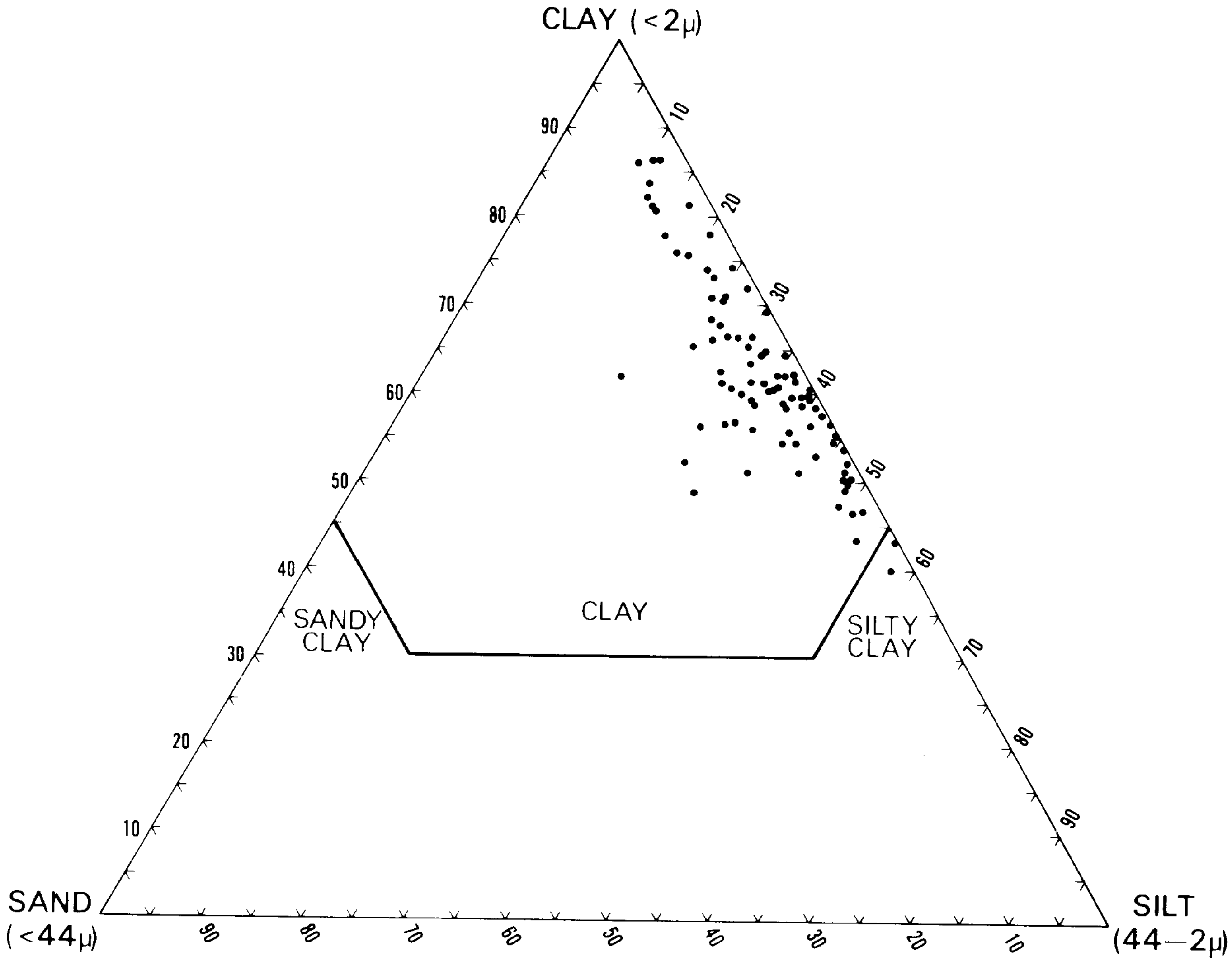

Figure 1. Sand (>44μ), silt (44-2μ), clay (<2μ) diagram for all samples from the Red Clay.

(Jackson, 1956, p. 101).

DISCUSSION OF PARTICLE SIZE RESULTS

Reference to Figure 1 (sand, silt, clay triangular diagram) will serve to characterize the particle size distribution and variation in the Red Clay material. Sand/silt/clan mean values (derived from Table 1) and their standard deviations are: Sand; 4% ± 4%; Silt; 32 ± 11%; Clay; 62% ± 11%. Since silt and clay are the main components they must vary together such that when one goes up the other must go down. The silt/clay ratio varies from 0.28 to 0.87 with the mean ratio at 0.52 using the standard deviation limits given above. The 62 samples of Table 1, with the exception of one or two extremely sandy samples all fall within the range of materials classified as clay, although some of the siltiest samples are in the silty clay field on the triangular diagram, Figure 1. There will be a correlation between the mineralogy and the particle size distribution since the clay minerals are concentrated in the finer sizes below 2μ and 0.2μ and the quartz, feldspar, carbonate minerals are largely in the silt size range. For instance, there is a moderately strong correlation (r=0.65) between the silt content and carbonate content of those Red Clay samples for which carbonate amounts were determined.

Since sand tends to be low in amount and is not the active fraction in these materials it is of interest to plot the silt (20-2μ), coarse clay (2-0.2μ), and fine clay (<0.2μ) on a triangular diagram (Figure 2). The mean percentage values for 61 samples are: silt; 43, coarse clay; 43, fine clay; 24, with standard deviations of 13, 7, and 9 respectively. But there is a decided

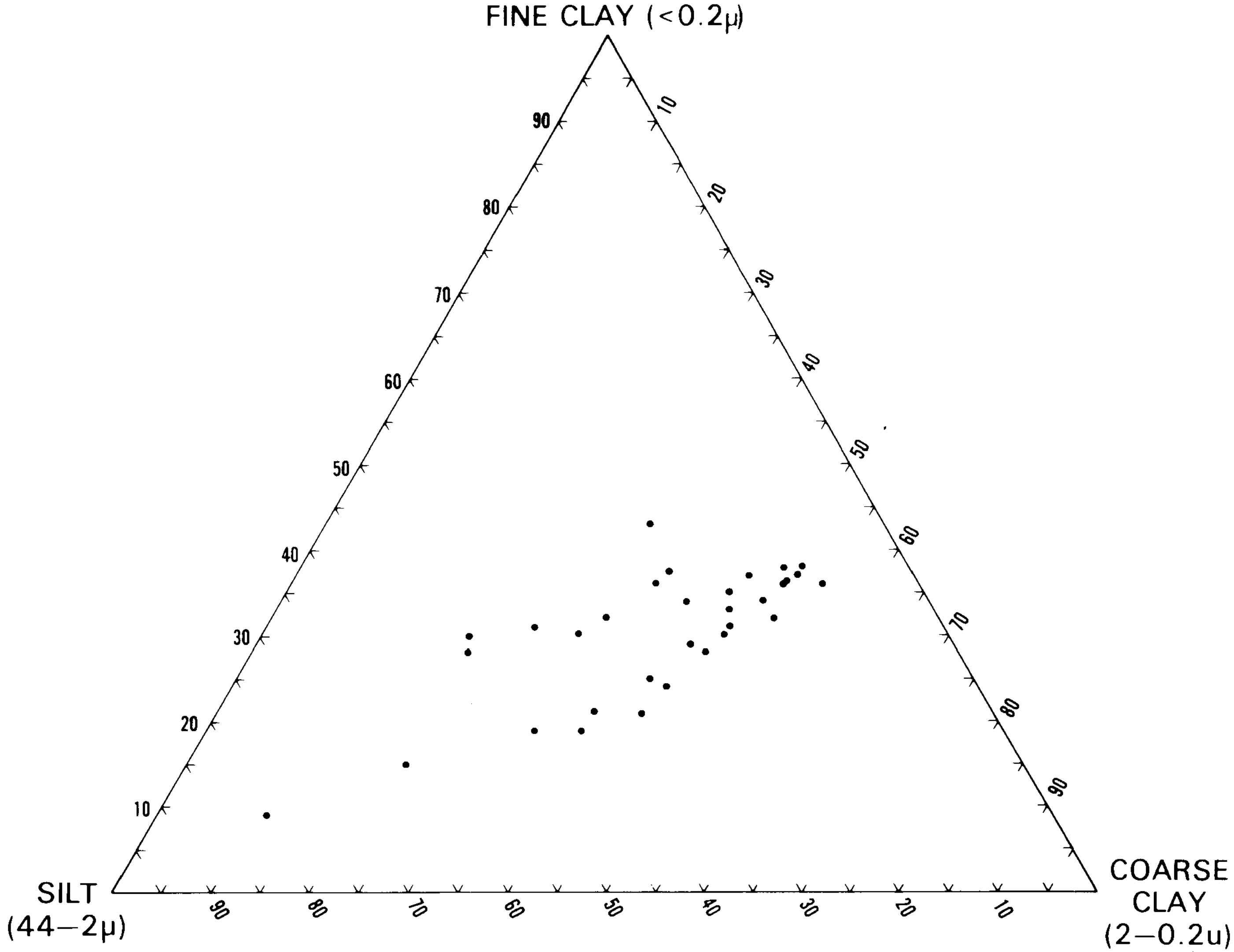

Figure 2. Silt (44-2μ), coarse clay (2-0.2μ), and fine clay (0.2μ) diagram for holes 4236-4284 and 4689-5103.

difference in the fine clay amounts in the samples worked on by Brown and those worked on by Meyers. This difference is statistically significant. Samples 4236-4284, and 4689-5103, worked on by Brown, have a mean fine clay content 29.9 with a standard deviation of 7.1. The samples of 4586-4613 worked on by Meyers have a mean fine clay content of 17.3 with a standard deviation of 6.1. The difference between the two means is 12.3 which is about two standard deviations and would indicate that the difference is not random but real. This difference in the means is apparently due to laboratory procedure since there is not a corresponding significant difference in the mechanical data from the two data sets. For instance the mean of Plasticity Index values for the "Brown" samples is 32.9 with a standard deviation of 10.5 and the similar mean for the "Meyer" samples is 32.4 with a standard deviation of 6.7. These two sets are from the same population. Also the total clay (<2μ) amounts are not significantly different in samples from the two laboratories. The overall mean clay content for the "Brown" samples is 67.3, SD = 15.5, and for the "Meyer" samples the mean is 59.0, SD =7.3. The difference in the means of 8.3 is considerably less than two standard deviations. This is to say then that one or both groups of values for fine clay amounts is considerably in error. Since the "Meyers" fine clay data does not correlate nearly as well as the "Brown" data with the Plasticity Index and the Liquid Limit data the "Meyers" fine clay data will not be used in the balance of this report. The triangular diagram (Figure 2) showing silt, coarse clay, and fine clay from the 32 "Brown" samples indicates a relative uniformity in the coarse clay/fine clay ratio which is close to 60/40. The greater variability in the silt content shows on the diagram as an elongate trend perpendicular to the silt base.

MINERALS IN THE RED CLAY

TYPES AND AMOUNTS OF MINERALS

The determination of the types and amounts of different clay and non-clay minerals was carried out by x-ray diffraction. The assemblage of clay minerals in the Red Clay is similar from place to place and from different depths in a single location. That is, the Red Clay contains similar clay minerals in all of the locations so far sampled. The principle clay minerals are smectite, illite, and chlorite. These are species stable under conditions of neutral to alkaline pH's and relatively high concentrations of cations such as calcium and magnesium. Very little, if any, kaolinite is observed (its presence in small amounts is obscured by the presence of chlorite) and there is only minor occurrence of interlayered clay minerals. The quantities of illite, chlorite and smectite reported in Table 1 for each sample come from the following:

(% clay species in silt) x (%silt) + (% clay species in co. clay) x (% co. clay) + (%clay species in fine clay) x (% fine clay) = total % clay species.

In the silt and coarse clay there are non-clay minerals (quartz, feldspars, carbonates) present and the quantities present have been determined by internal standard x-ray diffraction methods. In the silt and coarse clay the relative proportions of the clay minerals are estimated from x-ray diffraction peak heights. The quantity (100-sum quartz + feldspars + carbonates) is put equal to the sum (chlorite + illite + smectite) and in this way the relative clay proportions derived from diffraction peak heights, can be turned into weight percentages.

Table 1 reports only relative clay mineral percentages for the samples analyzed by D. Meyers. He determined the relative proportions chlorite/illite/smectite in the fine and coarse clay fractions but did not determine the amounts of non-clay minerals present and so the relative proportions cannot be converted into weight percentages of the whole sample.

The triangular diagrams (Figures 3 and 4) serve to summarize the proportions of clay versus non-clay minerals in the Red Clay and the proportions of illite to chlorite to smectite in the fine clay (where no non-clay minerals are detected). Figure 3 depicts clay minerals versus primary minerals where mean and standard deviation values are: Quartz + feldspars; 34 ± 6, Carbonates; 12 ± 6, Clay minerals; 53 ± 6. Figure 4, based on both Brown and Meyers data, depicts the smectite/illite/chlorite proportions in the fine clay and the mean and standard deviation values are: smectite; 53 ± 9, chlorite; 23 ± 6, illite; 23 ± 5.

CORRELATION OF PARTICLE SIZE DISTRIBUTION AND CLAY MINERAL TYPES WITH LIQUID LIMIT AND PLASTICITY INDEX DATA

A number of least squares fits and correlations were determined for the quantities referred to in the above title. Representative of these are the following:

1) Plasticity Index (PI) versus % total (<2μ) clay. The data points are plotted on Figure 5 along with the least squares

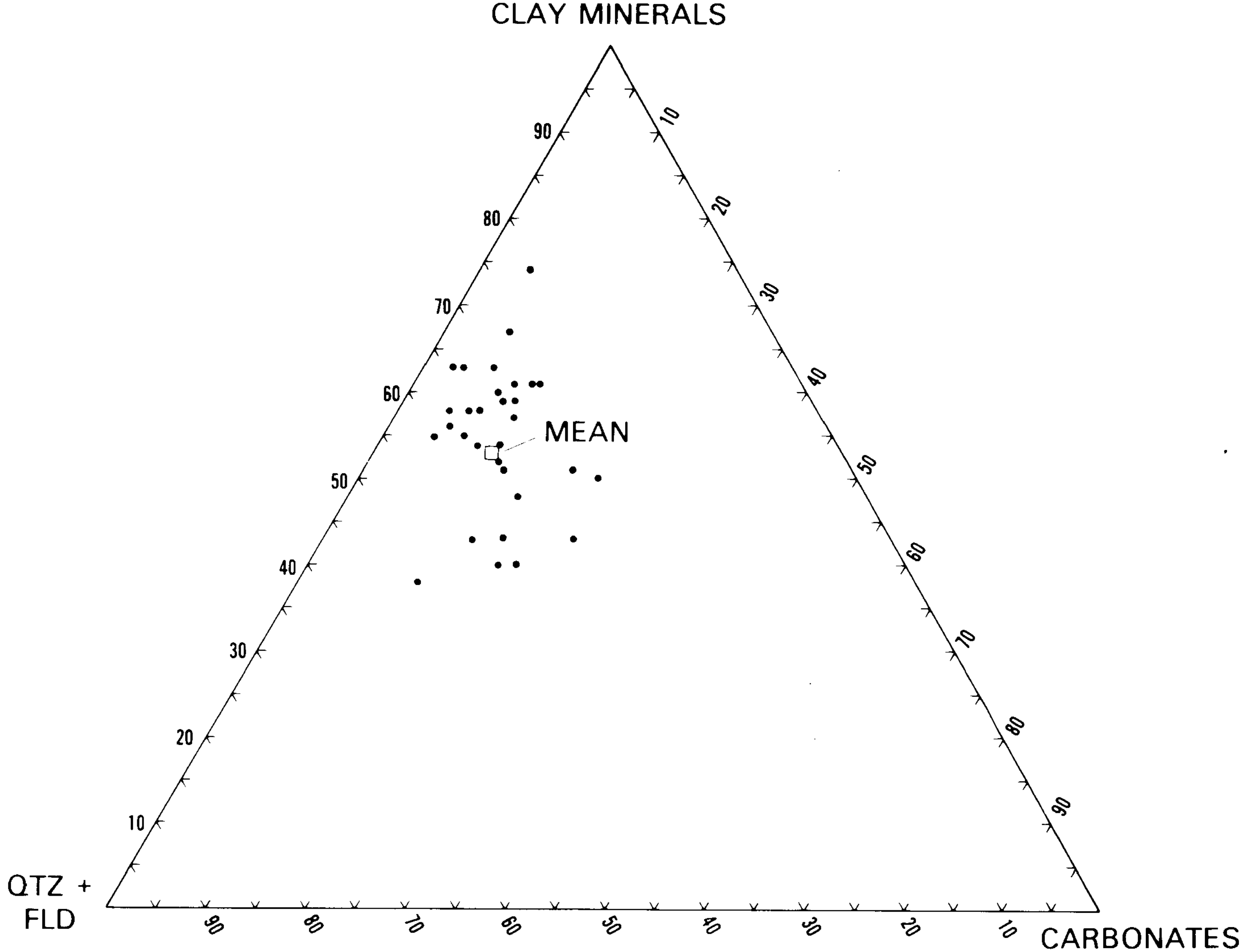

Figure 3. Quartz/feldspar, carbonate, and clay mineral amounts in the Red Clay Drill holes 4236-4284 and 4689-5103.

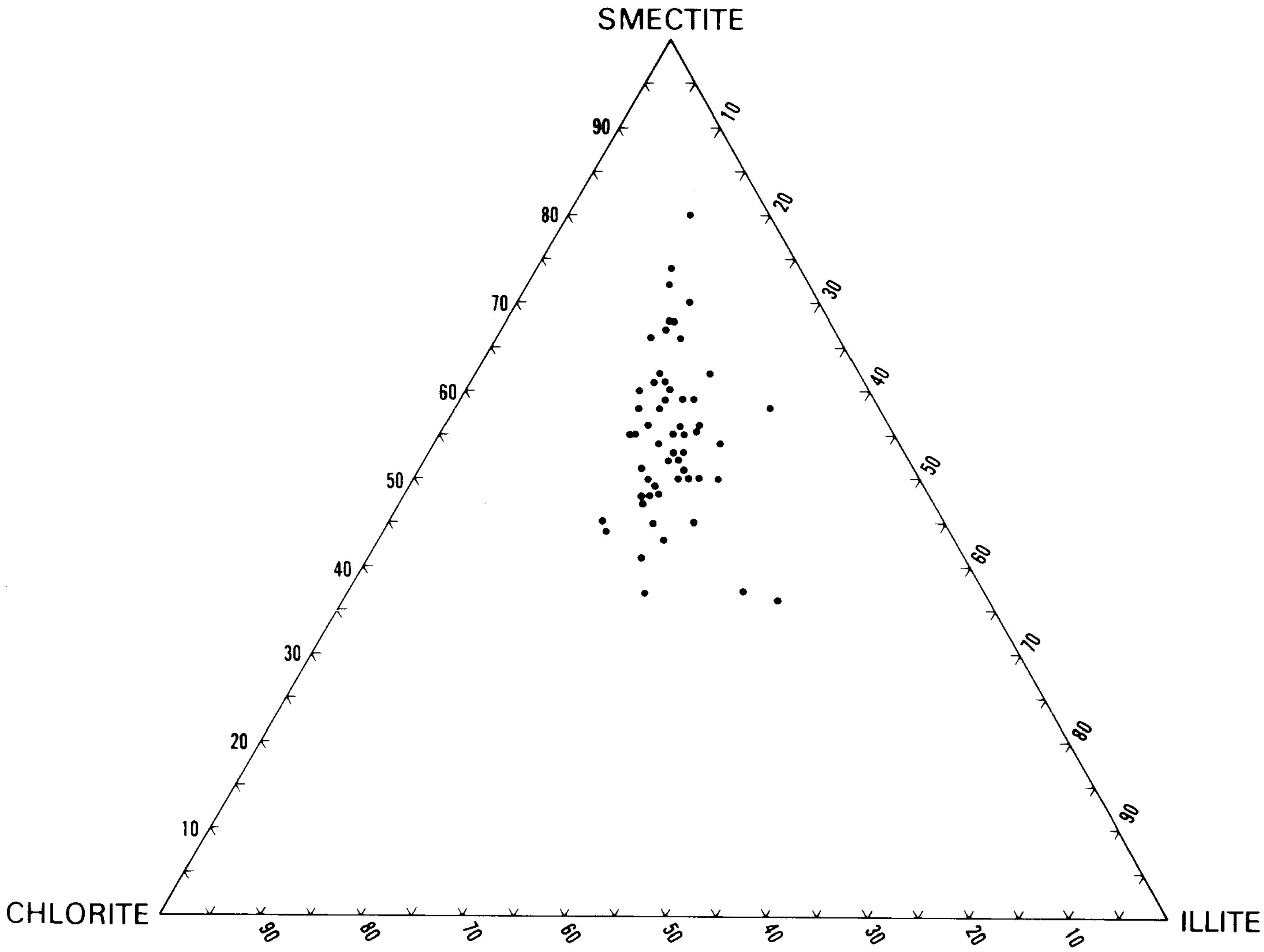

Figure 4. Chlorite, illite, smectite amounts in the <0.2μ clay. All drill holes included.

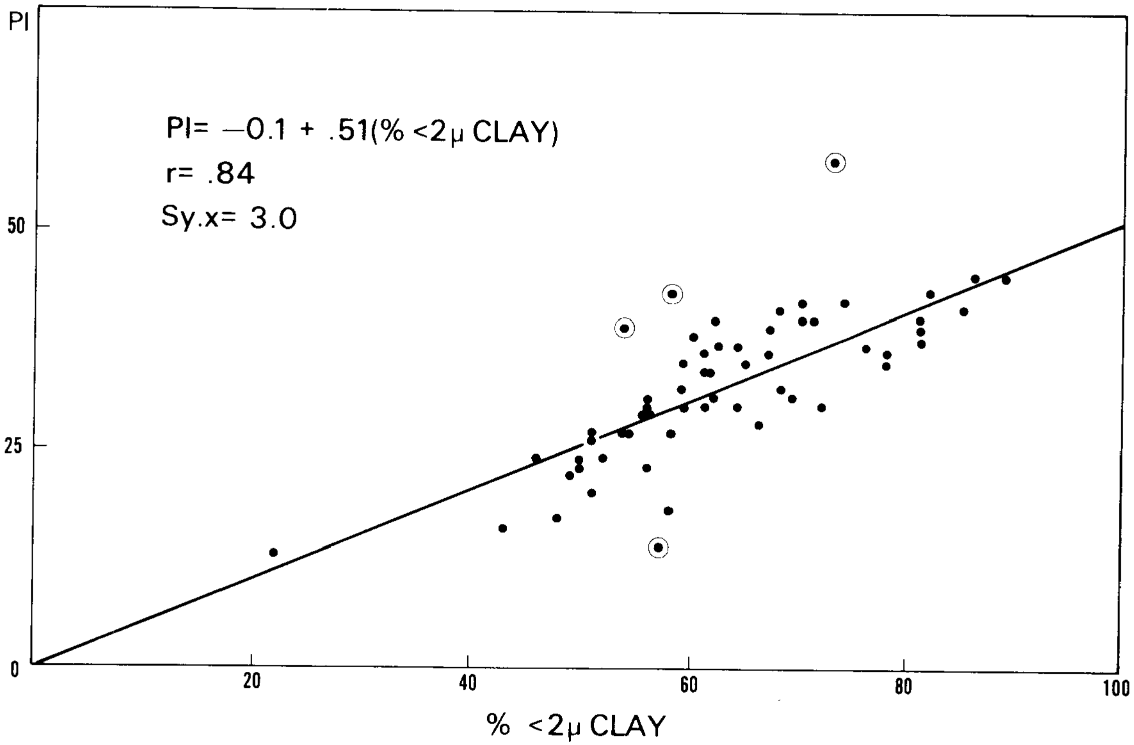

Figure 5. Plasticity index versus percent <2μ clay. All data included.

line. The equation for the line, its correlation coefficient and the standard error are:

$PI = 0.1 + 0.51\ (\%<2\mu\ clay)$

$r = .84$

$Sy.x = 3.0$

Four data points, circled on Figure 5, were not used in the least squares calculations.

2) Plasticity Index versus % fine clay ($<0.2\mu$).

Surprisingly the correlations for this relationship are in general not improved from the correlations in (1) above. The equations, correlation coefficient, and standard error for the PI data and the fine clay amounts from holes 4236-4374 and 5077-5103 are:

$PI = 1.0 + 1.07\ (\%\ fine\ clay)$

$r = 0.73$

$Sy.x = 5.4$

3) Plasticity Index versus % Smectite (Figure 6)

This correlation also is as strong as (1). The equation, correlation coefficient, and standard error for samples from 4236-4274 and 5077-5103 are:

$PI = -0.9 + 1.6\ (\%\ smectite)$

$r = 0.85$

$Sy.x = 3.6$

The circled points were discarded in the correlation calculations.

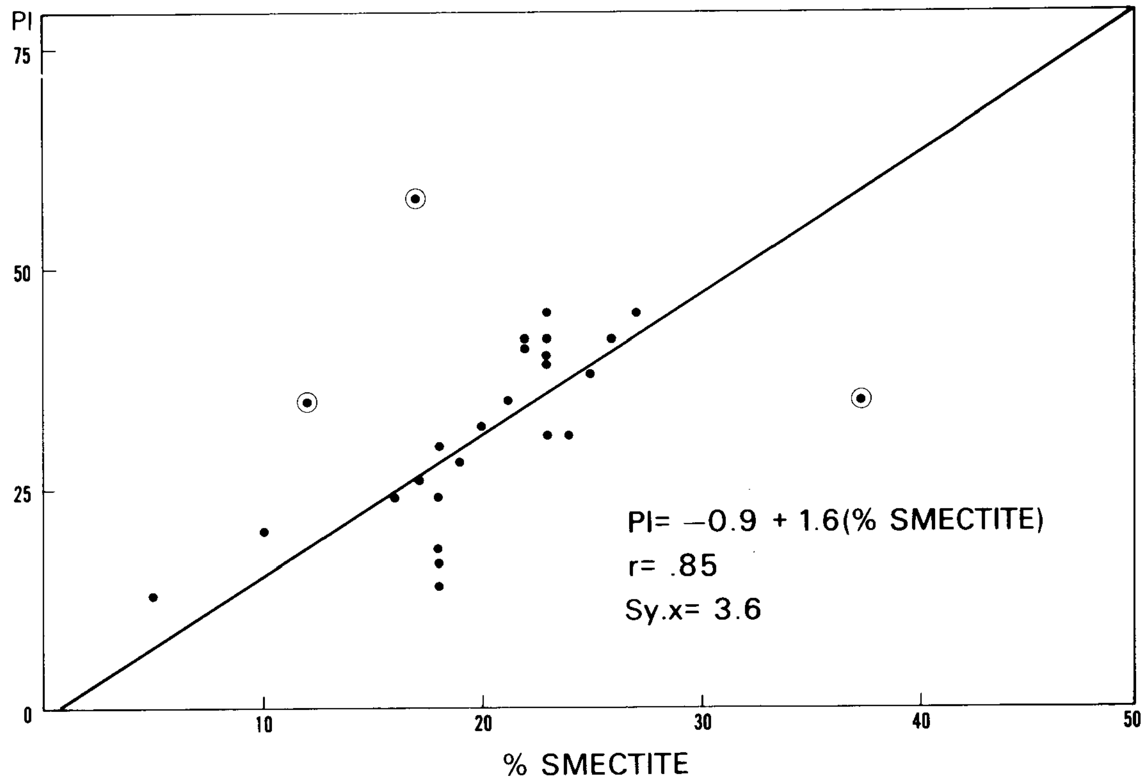

Figure 6. Plasticity index versus percent smectite. Data from holes 4236-4274 and 5077-5103.

4) Liquid limit versus total clay (<2μ) (Figure 7).

The relationship, correlations coefficient and standard error for all samples, except the circled point is:

$$LL = 10.0 + 0.78\ (\% < 2\mu\ \text{clay})$$

$$r = .76$$

$$Sy.x = 5.8$$

5) Liquid limit versus fine clay (<0.2μ), Holes 5077-5103.

This group of samples in which the fine clay determinations were done in a uniform way show a very strong correlation. The equation, correlation coefficient, and standard error are:

$$LL = 24.5 + 1.43\ (\% < 0.2\mu\ \text{clay})$$

$$r = 0.93$$

$$Sy.x = 3.7$$

6) Liquid limit versus smectite content.

One would expect high correlation coefficients for this relationship since the smectite clay is the most active clay mineral in the clay fraction. However the correlations although strong are not so strong as those relating the liquid limit to the fine clay as in 5) above. This is probably due to the difficulty in getting accurate smectite determinations by x-ray diffraction and may represent experimental error more than any lack of effect due to smectite content. Using just the samples from holes 5077-5103 which have the most uniform treatment the relationship is:

$$LL = 4.4 + 2.84\ (\%\ \text{smectite})$$

$$r = 0.83$$

$$Sy.x = 6.0$$

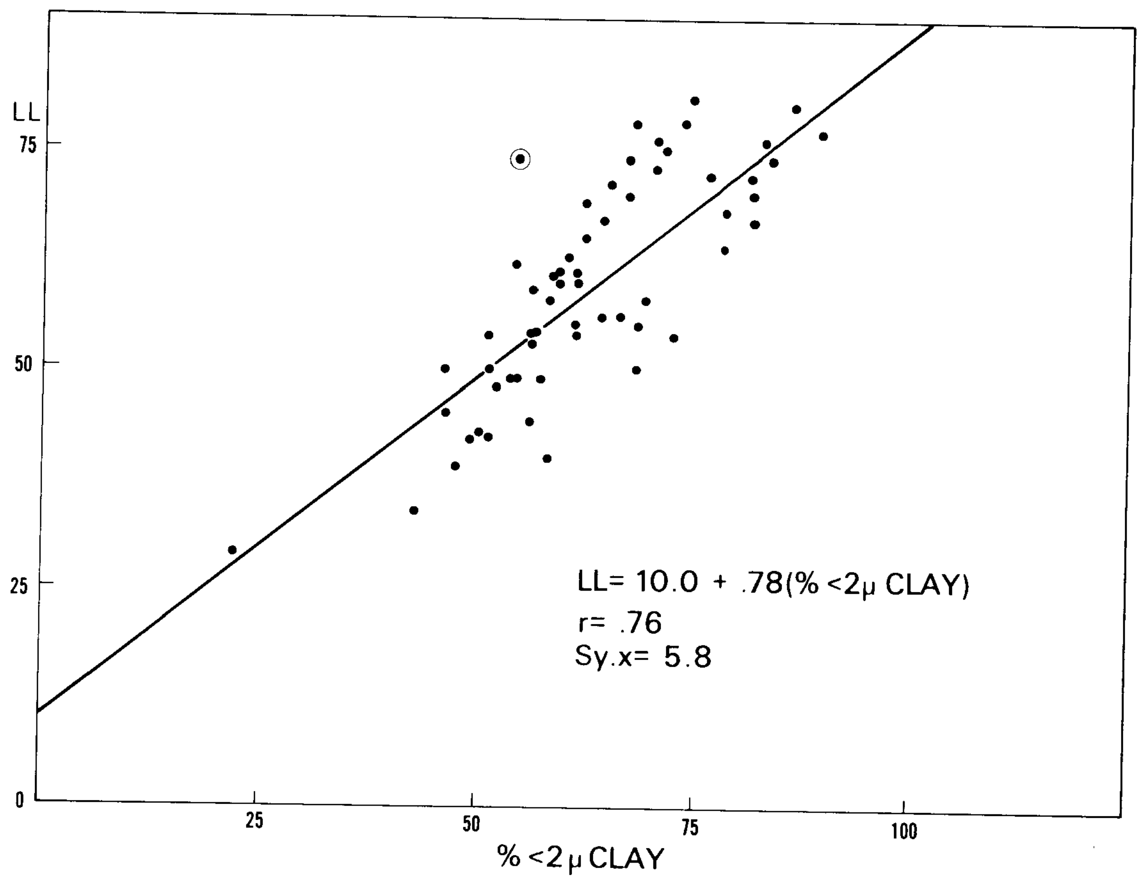

Figure 7. Liquid Limit versus percent <2μ clay. All data included.

The six equations developed above show, as expected, a strong relationship between the mechanical properties of the Red Clay its particle size distribution and its mineralogy. The most useful of the relationships developed above are those which relate the amount of <2μ clay to the liquid limit and the plasticity index, since the amount of this fraction of the clay is relatively easily determined as compared to the fine clay or the smectite contents.

SUMMARY

1. The clay fraction of the Red Clay is a uniform deposit with regard to mineralogy and size distribution. The major variations in the Red Clay are due to variations in the contents of silt and sand, and in the carbonate contents of the silt fraction.

2. There are strong correlations between mechanical behavior and size distribution and clay mineral content. The predictive relationships for the most important of these are:

   Plasticity Index = 0.1 + 0.51 x percent $<2\mu$ clay,

   Liquid Limit = 10 + 0.78 percent $<2\mu$ clay.

Table 1. Size distribution, mineral contents, and mechanical parameters of Red Clay Samples

Sample	% Sand	% Silt	% C. Clay	% F. Clay	% Quartz	% Feldspars	% Carbonate	% Illite	% Chlorite	% Smectite	PL	LL	PI
4236 19.5	2	47	21	29	20	13	25	11	11	16	21.4	45.5	24.1
4236* 24.5	7	30 29	32 31	30 29	15	11	10	18	19	24	23.7	54.0	31.0
4236* 29.5	0.5	42 44	27 28	31 32	18	9	24	13	14	18	22.8	40.3	17.5
4236* 34.5	4	48 49	21	27	19	8	20	10	15	18	22.6	39.4	16.8
4236* 49.5	3	32 30	41 38	24 22	23	14	5	13	27	12	36.2	71.2	35
4236* 54.5	4	23 24	32 33	41 43	20	14	4	22	21	17	27.5	78.0	58.5
4236 59.5	41 40	36 35	13	9	48	16	3	9	8	5	16.1	28.6	12.8
4278 7	4	23	36	36	19	26	11	13	29	18	24.6	54.3	29.7
4278 12	6	25 24	35 34	34 33	28	12	10	16	30	23	27.1	58.2	31.0
4281 8'	10	22 21	37 36	31 30	21	17	13	12	32	20	22.9	54.7	31.8
4282* 9'	6	15	43 42	35 34	22	16	13	17	25	21	29	63.7	34.7
4283 8'	46 53	43 49	6 7	5 6*	60	26	1	3	4	2	-	-	-
4284 7'	18	31 30	26 25	25 24	32	19	12	14	15	10	22.1	42.5	20.4

*Mineral per cents do not include contributions from the sand fraction

In samples 4586-4613 % numbers have relative validity only. (refers to % Illite, % Chlorite, % Smectite)

Sample	% Sand	% Silt	% C. Clay	% F. Clay	% Quartz	% Feldspars	% Carbonate	% Illite	% Chlorite	% Smectite	PL	LL	PI
4586 23.5	0.5	39	49	12	ND	ND	ND	18	30	12	24	53	30
4587 4	4	35	43	18	ND	ND	ND	19	25	19	36	76	40
4587 22.5	0.3	31	54	16	ND	ND	ND	19	25	19	36	76	40
4588 3	0.5	44	42	14	ND	ND	ND	11	13	17	25	54	29
4589 21.5	5	38	43	16	ND	ND	ND	13	22	17	29	61	32
4590 1	2	44	45	9	ND	ND	ND	13	22	14	22	49	27
4590 9.5	2	51	36	10	ND	ND	ND	12	16	13	21	45	24
4591 7.5	2	48	40	9	ND	ND	ND	17	15	13	21	42	22
4591 21.5	2	48	42	8	ND	ND	ND	13	22	12	20	43	23
4591 24.5	1	40	44	15	ND	ND	ND	13	25	20	30	60	30
4591 31.5	1	34	47	17	ND	ND	ND	13	30	19	30	67	37
4604 4.5	2	37	46	15	ND	ND	ND	14	23	18	24	60	36
4604 13.5	2	36	47	15	ND	ND	ND	17	21	18	32	69	37
4605 6	1	44	33	21	ND	ND	ND	11	21	16	22	49	27
4605 12.5	1	40	35	25	ND	ND	ND	9	25	20	25	63	38
4606 1	1	24	52	22	ND	ND	ND	15	17	36	39	81	42
4606 3	5	25	52	16	ND	ND	ND	14	27	22	37	78	41

Sample	% Sand	% Silt	% C. Clay	% F. Clay	% Quartz	% Feldspars	% Carbonate	% Illite	% Chlorite	% Smectite	PL	LL	PI	PENCT
4606 8.5	4	37	39	30				11	21	20	31	61	30	
4607 1	11	33	32	24				15	22	14	21	44	23	
4607 3	0.3	56	33	10				11	18	11	18	34	16	
4607 17.5	6	26	52	15				22	20	19	35	74	39	
4608 3	5	41	42	12				12	20	15	35	74	39	
4609 4.5	2	39	38	20				12	24	16	24	58	43	
4611 2	0.4	42	44	14				13	26	13	23	50	27	
4611 5.5	5	39	35	21				10	24	17	24	53	29	
4611 20.5	8	36	36	20				11	15	17	23	54	31	
4602 2	5	24	44	27				14	30	20	38	75	40	
4612 9.5	8	29	39	23				15	25	16	25	65	40	
4613 0	7	26	33	34							34	70	36	
4613 2	7	35	34	27							27	61	34	
4613 4.5	11	38	40	11							23	50	27	
4613 21.5	10	34	38	18							29	59	30	

Sample	% Sand	% Silt	% C. Clay	% F. Clay	% Quartz	% Feldspars	% Carbonate	% Illite	% Chlorite	% Smectite	PL	LL	PI
4689* 11.5	6*	16	46	32	18	18	6	13	18	22	ND	ND	ND
4689* 12.5	19*	20	38	24	14	14	11	10	15	18	ND	ND	ND
5077* 4.5	4*	24	44	27	17	16	16	10	17	18	ND	ND	ND
5077* 22.5	6*	13	47	34	14	14	7	14	23	23	33.7	72.4	38.7
5090* 5.5	2*	17	50	31	14	20	14	12	14	23	30	69.7	39.5
5090* 7.5	3*	30	43	23	ND	ND	ND	10	18	19	27.6	56.0	28.4
5090* 16.5	5*	19	44	31	16	17	11	12	17	22	ND	ND	ND
5090* 24.5	6*	12	46	36	16	18	9	11	17	22	33.1	75.6	42.5
5091* 13.5	6*	13	47	34	12	12	6	13	24	25	28.7	66.6	37.9
5093* 5.5	1*	9	53	36	14	12	12	13	19	27	32.5	77.1	44.6
5093* 8.5	2*	22	46	30	16	15	10	14	21	23	35.1	72.1	37.0
5100* 2.5	2*	20	44	34	19	14	3	11	14	37	32.2	67.7	35.5
5100* 5.5	4*	25	42	28	16	14	11	11	17	26	31.2	73.2	42.0
5100* 17.5	3*	11	49	37	15	19	7	12	21	23	34.9	80.1	45.2
5100* 21.5	5*	11	48	35	15	17	8	11	22	22	33.2	73.8	40.6
5101* 6.5	1*	47	33	19	24	18	18	9	12	18	25	48.5	23.5
5102 6.5	-	43	38	19	22	17	21	9	13	18	35	49.2	14.2
5103 6.5	-	36	43	21	19	20	18	10	15	18	26.5	56.2	29.7
5103* 8.5	6*	43	31	20	19	21	14	9	14	17	27.7	53.9	26.2

*Mineral percents do not include contributions from sand fraction

THE EFFECTS OF RED CLAY TURBIDITY AND SEDIMENTATION ON AQUATIC LIFE IN THE NEMADJI RIVER SYSTEM

by

P. W. DeVore, L. T. Brooke and W. A. Swenson*

Red clay erosion in southwestern Lake Superior has been a natural process along shorelines and in tributary streams and rivers since decline of lake levels following the Pleistocene period. Exposure of the unconsolidated glacial lake deposits resulted in fairly high and constant rates of erosion long before man began to alter the landscape. Rates of erosion along the Lake Superior shoreline have averaged up to 3.1 meters/year since 1938 (1) with contributions of 2×10^6 metric tons of red clay soils annually (2). An additional 5.6×10^5 metric tons are added by stream erosion (3). There is evidence that rates of erosion were accelerated by logging operations during the late 1800's, but this increase probably did not add significantly to the impact of the red clays on the Lake Superior ecosystem.

Despite persistent turbidities and sedimentation in southwestern Lake Superior, the fishery has been historically productive. Lake herring (*Coregonus artedii*) seem to have thrived as the clays added nutrients to the somewhat sterile environment and the reduced photic zone concentrated the plankton (4). Not until introduction of rainbow smelt (*Osmerus mordax*) resulted in another planktivore selecting this same concentrated food source, which included larval herring, did herring stocks collapse (4,5). Walleye (*Stizostedion vitreum vitreum*) continue to benefit from the moderate turbidities in the lake and river mouths. The resultant low light intensities in the relatively productive inshore areas and broad shallows such as the Duluth-Superior estuary allow walleye stocks to reside in these waters without retreating to deep water sanctuary. The walleye population in southwestern Lake Superior is one of five stocks in the entire Great Lakes not experiencing declines (6). Red clay turbidity is a possible contributor to this stability.

Nutrient inputs to Lake Superior due to red clay erosion may have had a significant impact on production before settlement of the basin, but orthophosphate loading today from shoreline and stream erosion (302 metric tons annually) is only 3.7% of the contribution from industrial and municipal wastes in the Duluth-Superior area (7). Contributions of metals and other solutes are also insignificant when compared to present loadings from other sources (8). An exception to this is silica, which is loaded at a rate of 14,400 metric tons per year. This may be an important element in maintenance of diatom populations, the primary group of phytoplankton in Lake Superior. Silica depletion

*CLSES

in Lake Michigan may have contributed to limitations in diatom production in those waters (9).

The only detrimental effects which have been well identified from moderate rates of sedimentation are those on salmonid reproduction. Substantial rates of flow must occur through the gravel for selection by the female as a spawning site (10,11) and for survival of eggs and emergence of fry (12,13,14). Reviews of adverse effects on the benthic fauna (15) do not identify any effects of low level sedimentation, perhaps because such studies are rare in the literature.

The Nemadji River System produces 89% of the total erosional material of streams entering Lake Superior from Wisconsin. The study of aquatic life in the Nemadji River was begun with the realization that red clay erosion: 1) had minimal direct physical impacts on aquatic life in Lake Superior, 2) resulted in spatial redistribution of organisms and affected species interactions in Lake Superior, 3) was a fairly general characteristic of the Nemadji watershed with few areas severely aggravated by man (90% of the watershed is second growth forest), and 4) resulted in low turbidity levels which seldom exceeded 100 ftu's (65 mg/l).

The effects of turbidity and sedimentation on aquatic life have generally been studied in situations where there are massive movements of soils (e.g. logging operations, poor agricultural practices over large areas) or a source of inorganic sediment (sand pit washing, mining clay wastes, etc.). The burden of sediment which is discharged into stream and river systems under these conditions has afforded excellent opportunities to assess the direct and indirect effects of extremely high levels of stream sedimentation on aquatic life (16,17,18). Few studies, however, have measured the effects of erosion and the resultant turbidity and sedimentation which occur naturally in a young river system flowing through highly erodable bed materials such as is the situation in the glacial lake deposits characterizing the Nemadji River Basin. This study offered the unique opportunity to assess the effect of relatively low level sedimentation in such a system.

NEMADJI BASIN STUDY AREA

The Nemadji River Basin includes 740 km^2 (460 mi^2) in Carlton and Pine Counties, Minnesota and Douglas County, Wisconsin. The basin is essentially a level plain representing a portion of the abandoned lake bed of glacial Lake Duluth. Lake deposits of clay, silt and sand comprise the central portion of the Nemadji watershed. The Nemadji is a young river meandering through a level plain of highly erodable lake sediments. Land use is 90% second growth forest. The area was clearcut in the early 1900's and is now predominantly regrowth of aspen, birch and some pine (19).

Two tributaries to the Nemadji River were selected for implementation of erosion control measures and were of primary interest to this study. These are the Skunk Creek Basin in Minnesota, a relatively high sediment-producing watershed covering 17.2 km^2 (10.7 mi^2), and Little Balsam Creek in Wisconsin, a moderate sediment-producing basin covering 9.7 km^2 (6 mi^2). Skunk Creek remains relatively turbid year-round. Stream discharge varied from 0-5.78 cms (0-204 cfs) in April-September 1976. The average gradient is 6.25 m/km (33 ft/mi). Little Balsam Creek is a relatively clear trout stream which maintains a more stable discharge [0.02-1.87 cms (0.75-66 cfs) in November 1975-September 1976]. Average gradient is 20 m/km (105 ft/mi). Land use within both watersheds is of relatively low intensity. The primary sediment producing problems are stream bank and roadside erosion.

Site Selection

Thirteen study sites were initially selected in the Nemadji River, Balsam Creek, Little Balsam Creek, Empire Creek, Skunk Creek, and Elim Creek. These sites were chosen to represent stream and river channel types which typify the Nemadji River watershed. After 1975, four sites (nos. 2,3, 6,7) were eliminated due to the redundancy of the information gained, the time requirements for adequate sampling and analysis of benthic samples, and the expansion of the project objectives to include more extensive monitoring of sites selected for intensive erosion control structures (i.e. nutrients, microbial populations, and primary production). After the first sampling period in 1976, site 1 (closest to the mouth of the Nemadji River) was found to be subject to periodic organic pollution from industrial sources. The response of the benthos was such that interpretation of the effects of erosion and sedimentation was meaningless. This site was thereafter sampled only to monitor fish movements.

Most of the interpretation of the effects of erosion and sedimentation is therefore restricted to 2 sites on the Nemadji River (sites 4 and 5), two sites on Little Balsam Creek (nos. 8 and 9), one site on Empire Creek (no. 10), two sites on Skunk Creek (nos. 11 and 13), and one site on Elim Creek (no. 12). Summaries of data on macroinvertebrate diversity, abundance, and biomass are presented on all sites, including those eliminated in 1975 and 1976, in the Appendices.

Site locations are shown in the gradient map of the Nemadji River and tributaries considered in this study (Figure 1). Initial site selection and site descriptions are as follows (Appendix A includes additional site characteristics):

<u>Site 1</u>: The Nemadji River 0.8 km (0.5 mi) upstream from its mouth. The channel is broad (46 m), deep (2.5 m)

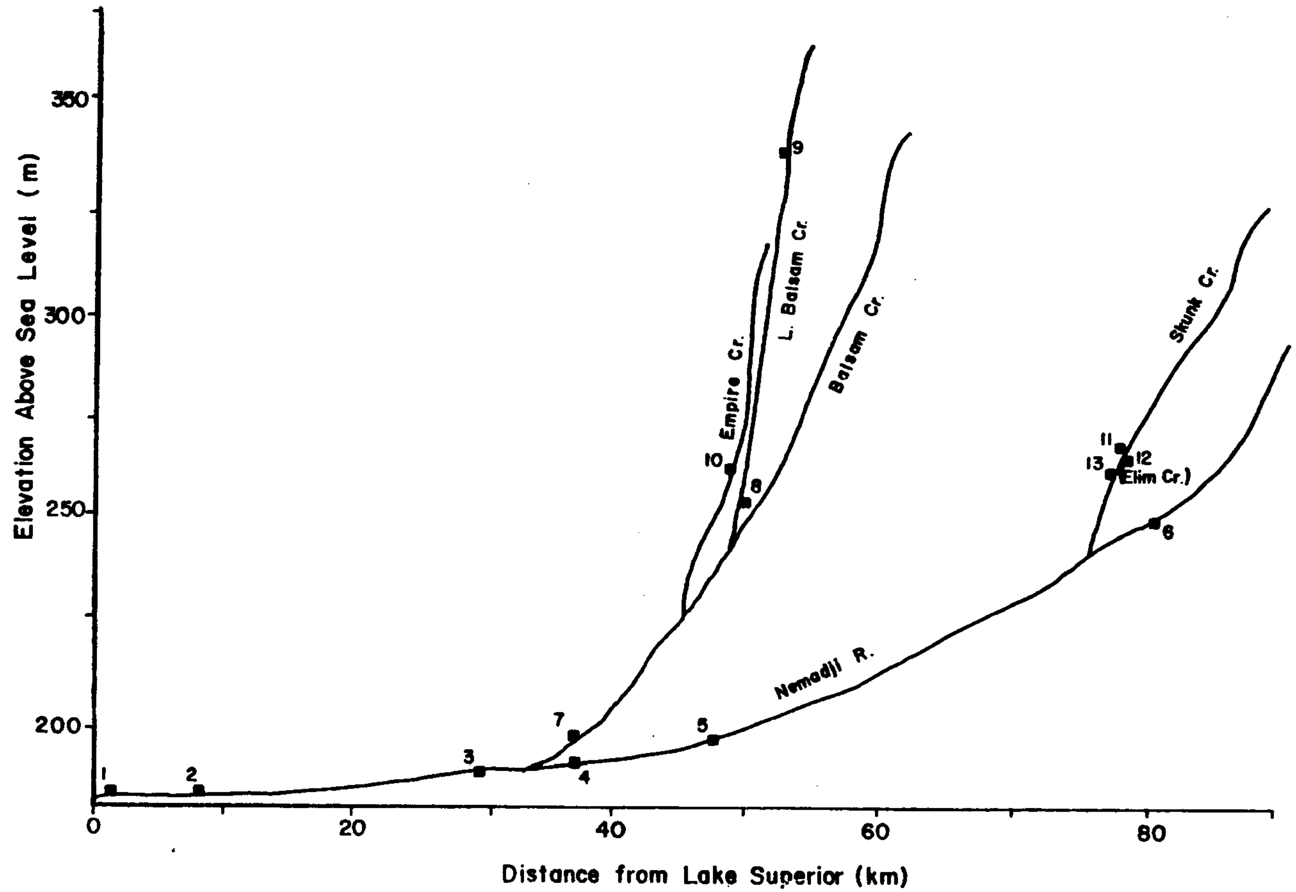

Figure 1. Gradient map of the Nemadji River and selected tributaries with location of sampling sites.

and of uniform shape. There is no definable gradient. Current and direction of water flow over the sand substrate is influenced by Lake Superior seiches.

Site 2: The Nemadji River approximately 8 km (5 mi) above the mouth. The river is narrower (22 m), deep (2.5 m average) and slow-moving. Currents and water levels are influenced by Lake Superior seiches. The stream bed is bordered by clay banks resulting in some erosion. The substrate is composed of clay, sand and some gravel.

Site 3: Approximately 30 km (18 mi) above the mouth. The river is shallow (<1 m) with a gradient 0.66 m/km (3.5 ft/mi). Average width is 11.3 m. Erosion of the banks in this region result in a predominantly unstable sand substrate.

Site 4: Nemadji River 35 km (22 mi) above the mouth is physically similar to Site 3.

Site 5: Nemadji River 47 km (29 mi) above the mouth. The river character changes to a pool-riffle pattern with rubble and gravel more prevalent in the stream bed. Average width is 20.7 m. Average depth is 0.5 m. Soils in this location are predominantly silts and clays resulting in a low sand bedload. The gradient is approximately 1.7 m/km (9 ft/mi).

Site 6: North Branch of the Nemadji River 80 km (50 mi) from the mouth. The river has a typical pool-riffle configuration with rubble and boulders prevalent in the substrate. Average width and depth are 11.7 m and 0.5 m respectively.

Site 7: Balsam Creek is classified as trout water by the Wisconsin DNR, but the reaches sampled are turbid throughout the year. The substrate has large quantities of rubble with heavy silt in the pools. Average width and depth are 8.0 and 0.6 m respectively.

Site 8: Little Balsam Creek below proposed erosion control sites. The substrate is gravel and rubble in riffles and sand in pools. There is some clay sediment but the stream remains clear aside from spring floods. The gradient is 20 m/km (105 ft/mi). Average width and depth are 3.7 and 0.25 m.

Site 9: Upper reaches of Little Balsam Creek well above the area planned for bank stabilization. Rubble and sand make up the substrate. Discharge is lower than in the previous station. Average width and depth are 2.0 and 0.15 m.

Site 10: Empire Creek which occupies an adjacent drainage basin to the Little Balsam with stream length, watershed size, and water quality very similar to the Little Balsam. The substrate is sand and small gravel with very little rubble. This undisturbed watershed was selected to allow more meaningful interpretations of changes in Little Balsam Creek associated with erosion control. Average width and depth are 2.0 and 0.25 m.

Site 11: Skunk Creek above the influx of Elim Creek (where a flood water retaining structure is being constructed) and above most of the bank stabilization and channelization planned for Skunk Creek. The substrate is about 35% rubble with silt and clay in the pools. Average width is 3.0 m. Average depth is 0.45 m.

Site 12: Mouth of Elim Creek which is an intermittent stream that is monitored when a stream flow exists to assess the effects of the proposed sediment retaining structure. The substrate is largely rubble and gravel.

Site 13: Skunk Creek below the proposed construction area, an area physically similar to Site 11, although there is more silt and clay and less rubble. The gradient is about 6 m/km (33 ft/mi). Average width and depth are 4.9 and 1.0 m.

Additional sites: Three additional sites were monitored for major nutrients beginning in August, 1976. These included two Skunk Creek sites and one Elim Creek site. The Skunk Creek sites were above and below the area to be impounded by the Hanson dam. The Elim Creek site was above the dam to be constructed on this tributary. These sites were included with nutrient monitoring information from sites 11, 12, and 13 to assist in interpretation of the effects of the dams on nutrient loads.

METHODS

Three products of erosion which affect the aquatic ecosystem are nutrient input, turbidity and sedimentation. Each of these factors has possible effects associated with it, as outlined in Table 1. Studies conducted in the Nemadji River System were designed to measure most of the potential effects.

Table 1. Potential Effects of Erosion on Aquatic Ecosystems

- Nutrient Input
- Turbidity
  - Reduced Light Penetration
    - Primary Production
    - Rooted Plants
  - Reduced Visibility
    - Inhibits Sight-Feeding Fish
    - Organism Interactions (Behavioral Changes)
  - Increased Substrate for Microrganisms

Sedimentation
- Direct Effects on Organism
  - Clogging Gills
  - Inundation
  - Fish Egg and Fry Mortality
- Change in Substrate
  - Cover Rocky or Riffle Areas
  - Eliminate Interstitial Space
  - Change Character of Substrate in Pools

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Chemical and Physical Characteristics

Dissolved oxygen, conductivity, turbidity, and temperature were measured each time a site was visited from August, 1975 through October, 1977. Dissolved oxygen and temperature were measured with a Yellow Springs Instrument Model 54 D.O. meter. Conductivity was monitored with a Yellow Springs Instrument Model 33 SCT meter. Turbidity was measured in Formazin Turbidity Units (FTU) using an Ecolab Model 104 Turbidimeter (Ecologic Instruments, Inc.).

Average width and depth at normal flow were measured at each site. Qualitative estimates of stream bank erosion, vegetative cover, and water color were made at all sites. The stream substrate was classified by visual appraisal according to the soil particle size classification described in "Biological Field and Laboratory Methods for Measuring the Quality of Surface Water and Effluents" (20).

The relationship between turbidity (FTU) and suspended solids (mg/l) was calculated by mixing varying amounts of red clay soil from the banks of the Nemadji River with Lake Superior water. The relationship was derived using 35 turbidity levels from 0.2 to 1000 ftu. Turbidity was measured with the turbidimeter, after which the sample was filtered through a preweighed Gelman A/E glass fiber filter (0.45 um). The filters were dried for 18 hr at 80°C and weighed. Filters rarely collected all the suspended solids. To account for this the turbidities of the filtrates were measured, and the difference between the initial and final turbidities of the samples was considered equivalent to the suspended solids collected on the filters.

The data was plotted and a line was fitted by the least square method (Figure 2). The equation for the line is:

$$Y = .61\ X + 4.1$$

Where Y is suspended solids in milligrams/liter and X is turbidity in formazin turbidity units. The correlation coefficient is 0.99.

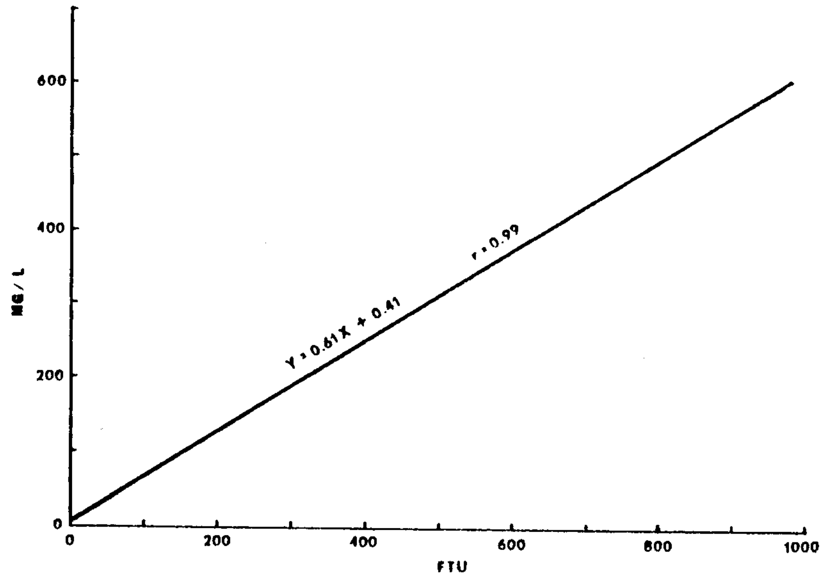

Figure 2. Relationship of mg/l suspended solids and formazin turbidity units (FTU) estimated from 35 turbidity levels between 0.2 and 1000 FTU.

Primary Production

Standing crop of periphyton on artificial substrates was measured in Empire, Little Balsam and Skunk Creeks during the ice-free months from late 1976 through August 1977 using chlorophyll a as an estimator. Four replicate glass slides (25.4 x 76.2 mm) at two depths (4 and 30 cm) and two positions (horizontal and vertical) were used as standard substrates for collection and analysis. Constant exposure depths were maintained by mounting the slides on a floating frame which compensated for limited variation in water levels. Three weeks exposure was used to allow sufficient time for colonization and growth to fairly stable levels (20,22). Slides were collected at site 8 on Little Balsam Creek and site 13 on Skunk Creek in September 1976. Collections were made at these sites and site 10 on Empire Creek and site 11 on Skunk Creek in October 1976 and May, June, July and early and late August 1977. Attempts to collect samples during the remainder of 1977 were thwarted due to repeated destruction of samplers by high water.

Slides were collected, emersed in 50 ml of 90% aqueous acetone, and kept cold in the dark until return to the laboratory. They were then stored at approximately $4^{o}C$ for 24 hours. Samples were only shaken, as the algae was composed entirely of diatoms which disrupt easily. Optical densities of the chlorophyll solutions were determined using a Perkin-Elmer Hitachi 200 spectrophotometer (after 10 minutes of centrifuging at 500 g). Readings were made at 750, 663, 645 and 630 nanometers (nm).

Chlorophyll a concentrations were determined after subtracting the 750 nm reading (to correct for turbidity) using the following formulas:

$$Ca = \text{concentration chlorophyll } \underline{a} \text{ in extract} = 11.64\ D_{633} - 2.16\ D_{645} + 0.10\ D_{630}$$

$$\text{mg chlorophyll } \underline{a}/m^2 = \frac{C_a \times \text{vol. of extract}}{3.87 \times 10^{-3}\ m^2\ \text{(area of slide)}}$$

A two-way analysis of variance was used to test for differences due to depth and angle of orientation within each station and sampling period. A three-way analysis of variance with site, depth and position as factors was not used as it consistently yielded significant three-way interactions, making interpretation of main effects invalid.

Microorganisms

Analysis of the microbial population of the Little Balsam Creek (Site 8), Empire Creek (Site 10), and Skunk Creek below Elim (Site 13) began in April 1977 and continued through January 1978. (see Appendix C for specific dates) Samples were taken at three week intervals during this period. Sampling began again during spring runoff in March 1978 and continued through the end of May 1978. Samples were collected in sterile whirlpacs and kept on ice until processing upon return to the laboratory. Microbial analysis of the water samples consisted of counts of total bacteria, fungi, and fecal coliform bacteria as well as identification of the major bacteria.

Five milliter dilutions of 1:10, 1:100, 1:1000, and 1:10,000 were filtered through 0.45 um membrane filters for enumeration of total bacteria. The filters were placed in sterile petri dishes containing an absorbant pad saturated with M-TGE broth (Difco). The samples were then incubated at 20°C for five days. This method of enumeration allows one colony to develop from one bacterium or cluster of bacteria. It therefore does not allow for the identification of more than one bacterium per clay particle.

Fungi was enumerated with the plate count method. The growth media used was Sabouraud agar (Difco). This agar provides a pH of 5.6 which promotes the growth of fungi and inhibits bacterical growth. The agar was added to sterile petri dishes containing either 2 ml of an undiluted water sample or 1 ml of 1:10, 1:100 or 1:1000 dilutions. The petri dishes were incubated for five days at 20°C, after which colonies were counted.

Fecal coliform bacteria were enumerated with 10 to 100 ml water samples. The procedure used was that for membrane filtration in "Standard Methods for the Examination of Water and Waste Water" (21).

Identification of the major bacteria in each stream was accomplished by isolation of the colonies and performing the following tests on each isolate:

1. Gram stain
2. Acid-fast stain
3. Endospore and capsule stain
4. Hydrolysis of gelatin
5. Reduction of litmus milk
6. Reduction of nitrates
7. Production of indole
8. MR-VP Test
9. Fermentation of carbohydrates (lactose, glucose, fructose)
10. Utilization of citrate, uric acid, and ammonium phosphate

Macroinvertebrates

Field Studies

Macroinvertebrates were collected with both bottom samples and artificial substrate samples at all sites. The use of an artificial substrate allowed comparison of sites with dissimilar substrates and demonstrated the effect of a stable substrate on insect abundance and diversity.

Six benthic samples were collected from each site during each sampling period. There were four sampling periods between August and November 1975 and three (spring, summer, and fall) in both 1976 and 1977. A total of 552 benthic samples were collected and analyzed. A sieving sampler (Surber Square Foot Sampler) was used except at sampling sites nearest the mouth where water depth exceeds 2 m. A grab sampler (Ponar dredge) was used at these sites. If both pools and riffles occurred at a site, three samples were taken in pools and three in riffles. Otherwise a transect of six samples was taken across the stream.

Artificial substrate samplers (Hester Dendy - surface area 0.11 m^2) were used at all sites. Two pairs of samplers were placed in the stream, one pair in a pool and one in a riffle (opposite sides of stream if there was no pool-riffle continuum), and left for six weeks. A total of 180 samples were collected. Sampling periods began in September 1975, and June and September, 1976 and 1977. The samples were collected by careful removal over a sieve to prevent loss of insects.

All samples were preserved in the field in 10% formalin or 70% isopropyl alcohol. They were washed in the laboratory through a U.S. Standard No. 35 sieve and hand picked. Generic identification of all insects was performed using keys by Hilsenhoff (23), Pennak (24), and Usinger (25).

The dry weight of all samples was measured after drying at 80°C for 24 hr and cooling in a dessicator. The biomass of the chironomids was derived separately from all other invertebrates, largely because of the necessity of previous separation for identification by examination of head capsules, but also to illustrate their importance in terms of biomass as opposed to total number.

Laboratory Studies

Laboratory studies were conducted to assess the effects of turbidity at different flow rates on respiration and activity of the stonefly, *Pteronarcys dorsata*. *P. dorsata* is a large insect and was fairly common in the Nemadji River.

Nymphs were collected in the Nemadji River in October and November, brought immediately to the laboratory, and acclimated to laboratory water temperatures (10-11 C). They were held under experimental conditions at a 12 hr light, 12 hr dark cycle for several days prior to testing. Nymphs were fed decaying leaves every two days.

Activity experiments: The activity experiments were conducted in the same glass experimental troughs used in the egg bioassay experiments. Water turbidity and flow rates were also maintained with the same system (see egg bioassay methods).

Animal movements were recorded using a Gilson Polygraph (Model ICT-5H). Four troughs with four chambers per trough (16 total nymphs) were used in each experimental run. The four channel polygraph was therefore connected through a timing switch which changed chambers, providing for monitoring of four replicates at each turbidity level for 15 min/hr. Two electrodes of stainless steel screen were submerged on opposite sides of each chamber and held in position by electrical spring clips (Figure 3). Any movement by the nymphs was recorded as pen deflections on graph paper. The type of movement recorded was observed to be whole body movement.

At least two experimental runs were performed at each of three water velocities, nominally 0.4, 0.8, and 1.5 cm/sec. Turbidities were nominally 1.5, 25, 60, and 150 FTU. These concentrations represent the range occurring season-

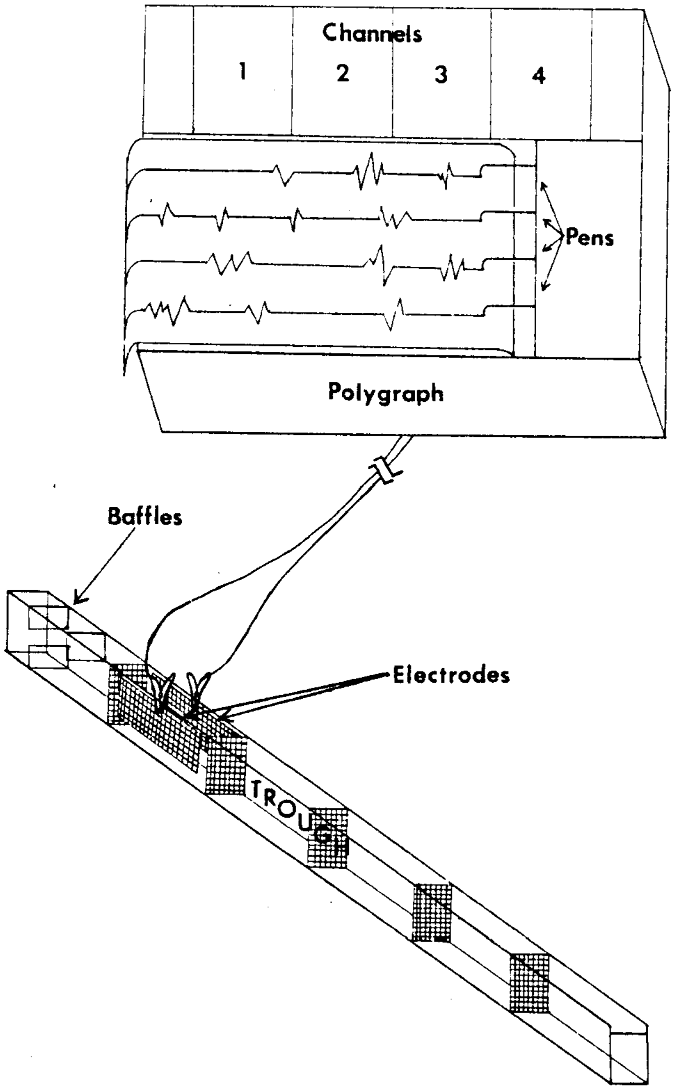

Figure 3. Laboratory apparatus used to measure response of *P. dorsata* illustrating electrode chamber and polygraph connection.

ally in the Nemadji River. With one exception, experiments were run for 24 hours. The 20/21 December experiment lasted 14 hr.

Respiration Experiments: Respiration rates were determined by a method similar to that used by McDiffett (26). Pint Mason jars were used as respiration chambers. Narrow sections of polyvinyl chloride (PVC) pipe were glued to the bottom of the jars to contain magnetic stirring bars. Plastic screens, supported by stainless steel wire platforms, were placed in jars to elevate the nymphs above the stirring bars and provide a substrate.

Water for each experiment was mixed to the desired turbidity level using red clay from the banks of Little

Balsam Creek and dechlorinated tap water. The water was aerated for several hours before experiments began to insure saturation.

Five respiration chambers were used for each experiment; four received insects and one served as a control. A measured volume of water was added to each chamber and the cover was carefully replaced to exclude air bubbles. A sixth sample was taken and fixed immediately for dissolved oxygen determinations.

The respiration chambers were kept at 6 C for two hours. Water in each chamber was stirred slowly with a magnetic stirrer. At the end of the incubation period, water was siphoned into 300 ml BOD bottles. Replicate dissolved oxygen determinations were made using the azide modification of the iodometric method (21). Samples were titrated over water of the same turbidity to aid in identification of the starch end-point.

The experiment was repeated five times at five different turbidity levels. The nominal turbidity levels were 2.5, 100, 250, 500, and 1000 FTU.

Fish

Field Studies

Field studies included monitoring of all sites for fish species composition, population size, total fish biomass, and evidence of reproductive success. Larval fish drift was also monitored each spring in the lower portion of the Nemadji River to assess the spawning success of Lake Superior species which utilize the watershed.

Fish sampling: Sampling was conducted at each site with electrofishing equipment or trap nets. Backpack electrofishing gear was used on Little Balsam, Empire, and Elim Creeks where water volumes were fairly small. The output mode most commonly used on these 350 watt units was 220 V. DC. A 1000 watt stream shocker was used in the mid-portion of the Nemadji River, generally 440 V. pulsed DC. Skunk Creek was fished with either unit, depending on water volume and accessibility. Fish were collected primarily with 24 hr sets of Minnesota Standard trap nets at the mouth of the Nemadji River where water depth averages 2.5 m.

All fish collected in the field were identified and counted and a random sample of each species weighed and measured to establish length-weight relationships within each stream. Scale samples were taken from brown trout (*Salmo trutta*) brook trout (*Salvelinus fontinalis*) and creek chubs (*Semotilus atromaculatus*) for comparison of growth rates between sites.

In the headwater streams of the Nemadji watershed (Empire, Skunk, Little Balsam, and Elim Creeks), 61 meters of stream was electrofished to sample a series of successive pool-riffle areas. Ten times the average width of the river was electrofished at sites on the Nemadji where the river was fairly wide. This insured inclusion of the different habitat types (pools and riffles generally occur at intervals of 5-7 times the stream width).

Population and biomass estimates were made at each site using the Delury fish-out method (27). Stream sections were electrofished three times in succession with no return of fish to that section until all sampling was completed. This allowed estimation of population size. Calculated length-weight relationships were used to estimate biomass.

Larval fish drift: Larval fish drift was monitored each spring (1976-1977) in order to estimate spawning success of the Lake Superior species which spawn in the Nemadji River. The Nemadji has spring runs of steelhead (*Salmo gairdneri*), longnose suckers (*Catostomus catostomus*), white suckers (*Catostomus commersoni*), shorthead redhorse (*Moxostoma macrolepidotum*), silver redhorse (*Moxostoma anisurum*), and rainbow smelt (*Osmerus mordax*). Most of the hatching fry of all species except steelhead drift passively downriver until they reach the lake, making possible rough estimation of total fry production if stream discharge is known.

Drift samples were collected with two drift nets, one set at the surface and one immediately below at 0.5 meters. The nets used in 1976 had a mouth opening of 30.5 x 14 cm. In 1977 nets were 40 x 22 cm. All drift samples were collected with 15 minute sets. Current velocity was measured at the mouth of each net with a Pygmy Gurley Current Meter. Daily discharge is monitored at this site by the U.S. Geological Survey. Their data was used to compute daily larval fish drift after drift densities had been calculated.

Sample collection began in early May in each year and was terminated in mid-June after the major hatches were gone. Two 24 hr periods were sampled in 1978, one during the peak of the smelt hatch and one during the sucker hatch, to assess drift periodicity.

All samples were collected at Douglas County Road 'C' due to the availability of discharge estimates and manageable water depths. This site is 18 km upstream from the mouth, but there is very little suitable spawning habitat below this point. The site was also felt to be far enough below most major spawning areas to eliminate the drift periodicity typical of sucker fry which initially emerge from the gravel at night. Subsequent 24 hr samples, however, demonstrated some diurnal periodicity.

Laboratory Studies

Laboratory studies were conducted to assess the impact on red clay turbidity and sedimentation of egg survival in walleye, rainbow smelt, and longnose suckers and habitat selection in turbidity gradients for brook trout and creek chubs.

Egg survival bioassay: A constant flow temperature and turbidity controlled apparatus was constructed for incubating fish eggs. The apparatus was essentially a gravity flow system (Figure 4). Water entered a common reservoir where temperature modifications were made before dividing the flow and increasing the turbidity in one half of the water supply to the desired maximum (4). The other half remained clear (2 FTU). Proportionate mixing of the turbid water with the clear water resulted in intermediate turbidities. Clay from the banks of the Little Balsam Creek (site 8) was used in the laboratory tests. Turbidity was measured with a Ecologic Instrument Model 104 turbidimeter.

Turbidity levels varied between years. The nominal levels sought were 0, 10, 25, 50 FTU in 1976 and 0, 25, 50, and 100 FTU in 1977 and 1978 (Table 2). The levels were chosen to simulate conditions which could occur in the Nemadji River during the time of rainbow smelt, walleye and longnose sucker egg incubation. Actual mean turbidity values were within 7.4% of the nominal values (Table 2).

The incubation chambers were constructed to allow simulation of stream substrate and current conditions. Two channels constructed of glass were used for each turbidity level with the channels subdivided into three sections by 530 μm stainless steel screen. Each chamber was 3 cm wide, 2.5 cm deep and 19.0 cm long. All of the channels were filled to a depth of 2.0 cm with sand or gravel ($\leq$ 20 mm but $\geq$ 10 mm in diameter). Both sand and gravel were used in 1976. Egg survival did not differ between substrates. Only gravel was used in 1977 and 1978. Each species of fish was incubated in two separate channels which differed in current velocity by a factor of approximately two. The means and ranges of the low and high flow velocities were 1.92 cm/sec (1.38-2.87) and 3.41 cm/sec (2.92-3.90).

Flow volume was measured using a stopwatch and graduated cylinder. Flow velocities were calculated using the formula $R = V/DW$ where R is flow velocity in cm/sec, V is flow volume in cm^3/sec, D is the mean water depth in the channel (cm) and W is the width (cm) of the channel.

Eggs and sperm were taken from more than a single individual of each sex except during 1977 when only a single female walleye was available (Table 3). The eggs were spawned into glass jars. Sperm was added to the eggs which were

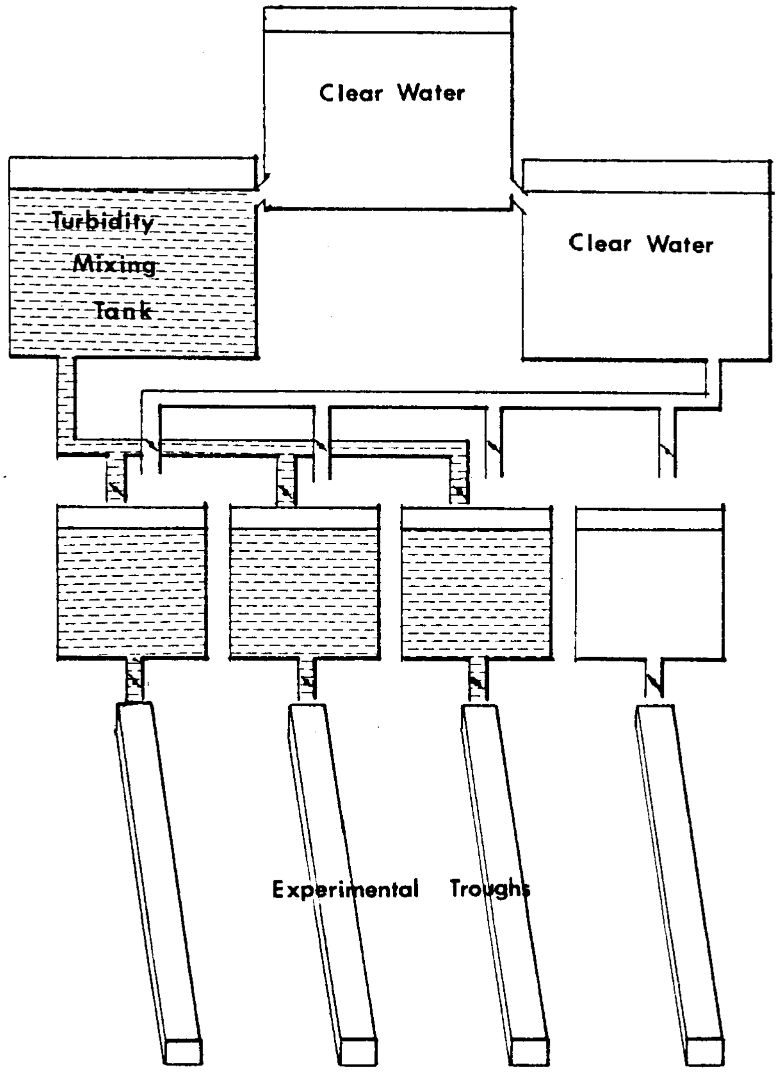

Figure 4. Constant flow egg incubation bioassay apparatus. Water entering the clear water tank is thermally modified prior to distribution to the clear water and turbid water mixing tanks. Turbid water is generated in the mixing tank by spraying water over clay balls. Proportional dilution is accomplished in four mixing chambers prior to delivering water at a controlled rate into the experimental troughs.

Table 2. Egg incubation experiment mean and nominal (in parentheses) turbidity, mean temperature, and duration. Experiments were conducted with eggs from rainbow smelt, walleye, and longnose sucker during 1976-1978.

Species of eggs incubated	Mean Turbidity (FTU)				Duration of test (days)	Mean Temperature(°C)
1976	(0)	(10)	(25)	(50)		
Rainbow Smelt	1.3	9.2	23.2	48.5	14	10.0
Walleye	1.0	9.3	23.5	49.9	24	10.3
1977	(0)	(25)	(50)	(100)		
Rainbow Smelt	2.0	27.2	52.8	100.9	16	8.4
Walleye	2.0	24.6	46.7	94.1	19	8.9
1978	(0)	(25)	(50)	(100)		
Walleye	2.2	23.1	46.3	96.2	21	8.8
Longnose Sucker	2.3	24.0	46.8	93.7	17	8.8

then allowed to "harden" before transport to the laboratory at the spawning temperature. When egg fertilization occurred in the laboratory, eggs were allowed to "harden" before placing them in the study chambers.

The studies were terminated before hatching occurred except the earliest hatch of rainbow smelt and walleye in 1976 which were observed passing through the incubation chamber screens. Rainbow smelt hatch (median time) in 34 days at 6 C, 27 days at 8 C and 19 days at 10 C (J. Howard McCormick, U.S.E.P.A. Environmental Research Laboratory, Duluth, Minnesota, Personal Communication). Walleye hatch (median time) in 34 days at 6 C, 27 days at 9 C and 15 days at 12 C (28). Longnose suckers hatch in 11 days at 10 C and 8 days at 15 C (29). In all cases termination of the studies occurred before the expected median hatch day (Table 2).

Water temperatures for incubation were near the midrange for successful incubation of each species. In all cases the incubation temperatures used were slightly lower than the optimum for survival.

Table 3. Location, date, water temperature and sex ratio of fish used to obtain fertilized eggs in egg incubation laboratory tests.

	1976	1977	1978
Rainbow Smelt			
Capture site of spawners	Alluoez Bay, Douglas County	Allouez Bay, Douglas County	
Spawning date	April 29	April 29	
Water temperature (C)	10.6	6.0	
Number females:Number males	5:8	5:8	
Walleye			
Capture site of spawners	Bad River Ashland County	St. Louis River Douglas County	St. Louis River Douglas County
Spawning date	May 7	May 4	April 28
Water temperature (C)	13.5	8.0	7.0
Number females:Number males		1:2	2:3
Longnose Sucker			
Capture site of spawners			Nemadji River Douglas County
Spawning date			May 2
Water temperature (C)			10 (estimated)
Number females:Number males			3:3

Gradient Selection: This study was designed to determine the responses of brook trout and creek chubs to levels of red clay turbidity similar to those occurring naturally in the Nemadji River System. These species were used as test organisms for the following reasons: 1) both species are locally abundant within the Nemadji River system; 2) they are associated with the headwaters of streams (30); and 3) in field studies brook trout were found primarily in clear streams while creek chubs were more abundant in turbid streams.

Brook trout used in the study had a mean length of 16.4 ± 3 cm. They were collected from Empire and Little Balsam Creeks. Creek chubs were collected in Skunk Creek, the Nemadji River, and Sargent Creek in St. Louis County. Fish were collected using a 350 watt backpack AC-DC current electroshocker. They were acclimated in the laboratory for a minimum of two weeks before being used in the behavior tests.

A continuous flow turbidity gradient tank was set up in a 610 cm x 46 cm tank. A 520 cm length of the tank was closed off with screens and divided into two sections. Plexiglass gates could be lowered to restrict movements between the two areas. White insulation board was placed over the tank and existing windows located on one side. Two regimes of turbidity were established within the tank during gradient experiments. Turbidities averaged 7.1 FTU in the upstream section and 61.1 FTU in the downstream section. Turbidities during the control runs when no clay was introduced averaged 2.3 FTU in both sections.

A layer of gravel was used for substrate. Twelve 180 mm lengths of 102 mm diameter PVC pipe were half buried in the gravel to provide uniform overhead cover in all sections. A 15-watt light bulb suspended in each of the four sections provided 4.4 ft-candles of light at the water surface. The lights were controlled using dimming and brightening equipment described by Drummond and Dawson (31). Natural photoperiods were used during the experiment. Viewing slits were cut in the insulation board above the level of the lights to allow observation of the fish and at the same time prevent the fish from seeing the observer.

Temperature was uniform within the chamber during each test but varied from 8.0 to 14.7 C through the course of the study. Clay used to produce turbid water was from the banks of Little Balsam Creek, part of the Nemadji River watershed.

Turbidity was maintained using the continuous flow clay turbidity source tank described by Swenson (4). Water was introduced into the gradient tank from the source tank or a clear water source by a series of 4 pipes. The 1st pipe was in front of the upstream screen 15 cm from the bottom and created a current in the tank. Pipes 2, 3, and 4 were buried in the substrate to create a spring-like situation. Clear water could be introduced through all the pipes and turbid water through pipes 3 and 4. Dechlorinated city of Superior water was used in the study.

Fish groups were subjected to either a control test (in which no clays were introduced) or the turbidity gradient. Fish were acclimated to the tank for two days prior to observations. Fish were then observed 7 times daily during the daylight hours for the following 2 days. During the observation periods the gates were lowered and distribution and use of cover was recorded. A mirror attached to a pole was used when necessary to find fish using the covers. Four brook trout or 20 creek chubs were used in each test. Four gradient trials and four controls were run with each species.

RESULTS AND DISCUSSION

Chemical and Physical Characteristics

Potential adverse impacts of red clay erosion on water quality have been identified as oxygen depletion and nutrient inputs (32). Adequate monitoring of oxygen levels in red clay areas has been conducted in this study to demonstrate that oxygen is not depleted by the red clays or associated organic compounds. The lowest level of oxygen saturation recorded was 54.6% (Table 4). Average saturation levels at sites with the highest mean annual turbidities (Skunk Creek) exceeded 92%.

Bahnick (7) showed that orthophosphate is removed from water by red clay in solution if it exceeds an equilibrium concentration of 0.06-0.13 mg/l. Turbid water sites on Skunk Creek had average orthophosphate concentrations within these ranges (Table 5). Clear-water sites (Empire and Little Balsam Creeks) had generally higher average orthophosphate levels than turbid water sites with the exception of Elim Creek and Skunk Creek downstream from Elim which appeared to be influenced by barnyard runoff.

Red clay, although not contributing significantly to orthophosphate levels in the watershed, may serve to transport these nutrients to Lake Superior when runoff from domestic and barnyard wastes causes phosphate concentrations to exceed the equilibrium concentration. Nutrient contributions from the Nemadji River watershed are relatively insignificant when compared to those from municipalities, however (7).

Primary Production

Estimates of the standing crop of periphyton in clear (Empire and Little Balsam) and turbid-water (Skunk Creek) tributaries were intended to identify the effect of turbidity

Table 4. Turbidity, dissolved oxygen, percent oxygen saturation, conductivity, and temperature ranges and means (in parentheses) at eight sites in the Nemadji River System for the period August 1975-October 1977 (sites are described in Appendix A).

Site Description	No.	Turbidity (FTU)	Dissolved Oxygen (ppm)	% Oxygen Saturation	Conductivity μmho/cm	Temperature °C
Nemadji R. (near mouth)	1	12-200 (51.6)	6.0-11.7 (8.6)	54.6-96.4 (80.2)	82-300 (186.4)	1.2-22.2
Nemadji R. (Central Portion)	4	7-300 (45.3)	6.0-13.4 (10.1)	54.6-112.0 (92.1)	99-280 (187.4)	1.3-25.0
Nemadji R. (Central Portion)	5	4-460 (51.5)	7.0-13.4 (10.5)	64.2-119.1 (96.1)	70-309 (172.8)	1.6-23.3
Little Balsam Cr. (Near Mouth)	8	2-63 (10.5)	9.2-12.8 (11.0)	88.2-123.1 (99.0)	48-182 (123.1)	1.8-18.2
Little Balsam Cr. (Headwaters)	9	2-9 (4.6)	6.7-12.2 (9.4)	57.4-107.6 (84.0)	30-179 (96.4)	1.5-16.2
Empire Cr.	10	1-28 (6.4)	9.4-12.8 (10.6)	85.1-105.7 (93.0)	47-191 (114.1)	1.5-12.8
Skunk Cr. (Above Elim)	11	12-200 (40.6)	8.8-12.4 (10.3)	80.0-113.0 (94.2)	43-232 (139.3)	0.5-21.1
Elim Cr.	12	4-500 (68.3)	8.0-12.8 (10.7)	79.4-124.6 (98.2)	110-276 (174.9)	1.9-20.0
Skunk Cr. (Below Elim)	13	10-500 (54.2)	7.0-12.7 (10.0)	70.5-122.1 (92.9)	59-238 (154.0)	0.3-21.9

Table 5. Nitrite, nitrate and ortho- and total phosphate, ranges and means (in parentheses) for ice-free periods between August 1976 and April 1978. (see Appendix B for complete data breakdown)

	NO_2 (ppb)	NO_3 (ppb)	$O\text{-}PO_4$ (ppb)	$T\text{-}PO_4$ (ppb)
Little Balsam	0.0[a]-74.50 (6.72)	0.0[a]-533.80 (88.47)	0.0[a]-868.37 (98.43)	0.0[a]-1219.17 (514.63)
Empire	0.0[a]-37.90 (3.28)	0.0[a]-263.54 (42.62)	0.0[a]-886.88 (96.10)	0.0[a]-1094.54 (307.03)
Skunk at Hanson Dam	0.0[a]-12.20 (1.02)	0.0[a]-126.93 (28.13)	0.0[a]-216.37 (62.93)	42.8-1160.54 (326.82)
Skunk Above Elim	0.0[a]-13.53 (0.85)	0.0[a]-56.38 (18.04)	0.0[a]-246.52 (39.76)	60.3-610.95 (242.35)
Skunk Below Elim	0.0[a]-42.30 (2.35)	0.0[a]-76.30 (18.91)	0.0[a]-535.57 (99.65)	38.8-1168.79 (463.43)
Elim Below Dam	0.0[a]-25.92 (5.29)	0.0[a]-161.21 (36.48)	0.0[a]-793.26 (200.59)	0.0[a]-1028.92 (623.07)
Elim Above Dam	0.0[a]-26.40 (5.45)	0.0[a]-338.88 (67.76)	0.0[a]-649.52 (144.23)	46.0-890.84 (540.06)

[a]Below minimum detectable level

on primary production. The influence of red clay turbidity on light penetration (4) and covering of suitable substrates as a result of sedimentation are effects which should reduce production in turbid waters. Confounding factors in comparing production between sites were the possibility of increased nutrient loads associated with higher turbidities and the higher average temperature in Skunk Creek. Concentrations of major nutrients, however, were found to be generally lower in turbid then in clearwater sites (Table 5). The measurements of standing crop in this study do not necessarily reflect the total amount of primary production in these tributaries. More suitable substrate for diatom attachment (more rock and rubble) occurs in both Little Balsam and Empire Creeks than in Skunk Creek. This study was therefore designed only to assess the effect of existing conditions within each tributary on production on a standard substrate.

Standing crop of chlorophyll *a* was plotted with data from 1977 preceding that from fall 1976 to demonstrate seasonal trends in primary production (Figure 5). The early increase in production in the spring and early decrease in the fall at the Skunk Creek sites is a result of minimal ground water

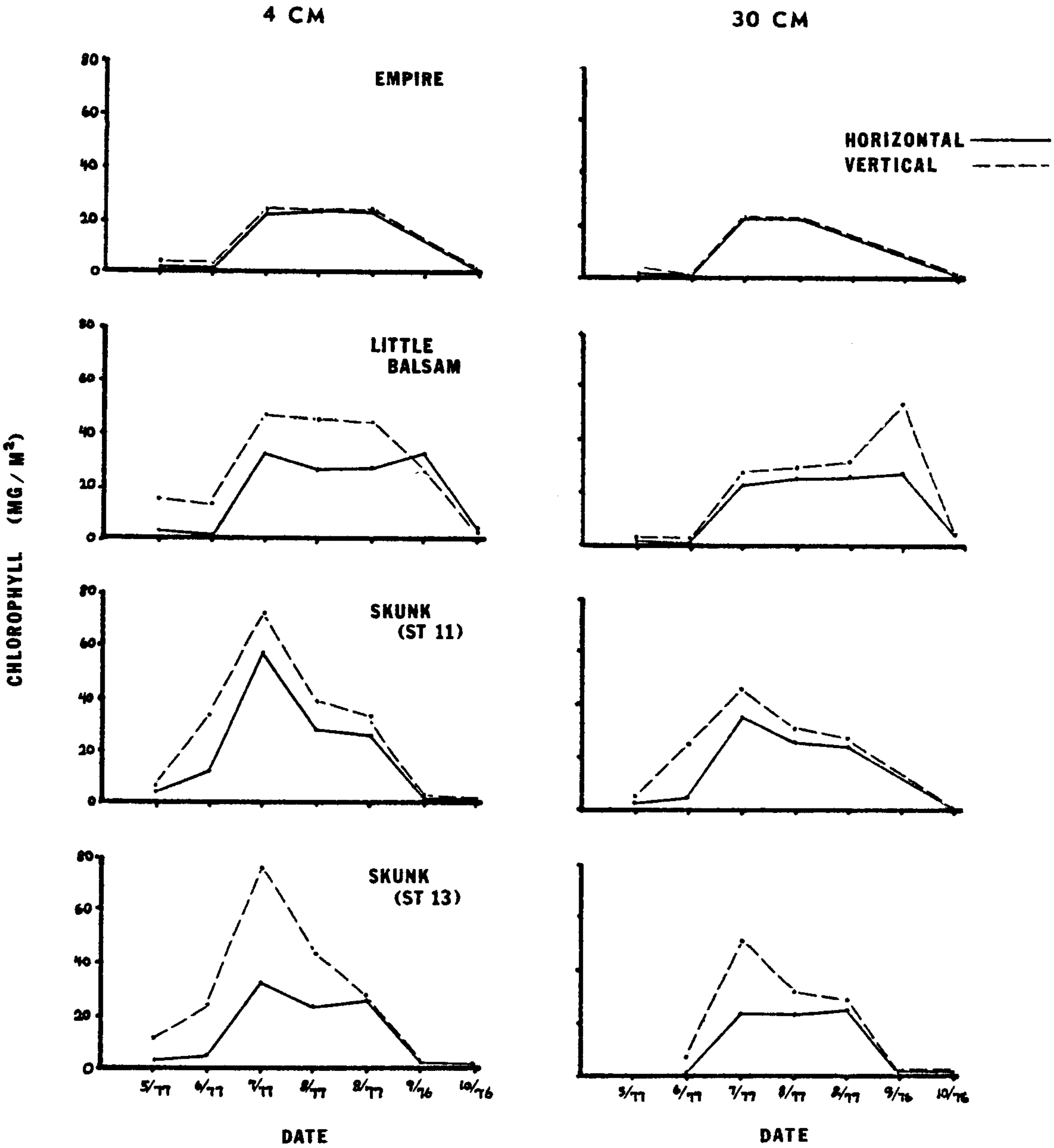

Figure 5. Mg/m^2 of chlorophyll a on glass slides at 4 and 30 cm and in Horizontal and Vertical Orientations in Empire, Little Balsam and Skunk Creeks.

discharge. Stream discharge in Skunk Creek depends primarily on run-off, and water temperatures are very responsive to ambient air temperature, warming more rapidly during spring and declining faster in the autumn. Empire and Little Balsam Creeks have much greater ground water discharges, resulting in more stable flows and cooler temperatures which are not as responsive to air temperatures.

Comparisons between chlorophyll a concentrations extracted from vertically and horizontally oriented slides showed chlorophyll to be significantly lower on horizontal slides at the Skunk Creek sites during all sampling periods (Table 6). Production was also significantly lower on horizontal slides on Little Balsam Creek during all 1977 sampling periods, but during 1976 production on the horizontal slides was generally higher (Table 7). This variation can be accounted for by the extremely low discharges which occurred in Little Balsam Creek during 1976. The reduced discharges resulted in minimal sedimentation on the slides. Empire Creek had significantly lower periphyton populations on horizontal slides in two of the four 1977 sampling periods. The May 1977 period was one of high stream discharge which resulted in sand sediment on the horizontal slides, thus decreasing production. Significant differences in June 1977 occurred when extremely low levels of chlorophyll were present (Table 7). When production was high (July and early and late August), there were no significant differences due to angle of orientation.

Empire Creek is the only watershed with no clay soils, and sedimentation was minimal except when discharges were high enough to transport sand to the water surface. In general the angle of orientation of the slides had little effect on periphyton production at this site. Differences in standing crop due to orientation were shown to be fairly pronounced at the other three sites, with differences about as great on Little Balsam Creek, which is characterized by very low turbidities, as in the relatively turbid Skunk Creek sites. Minimal quantities of silt and clay therefore resulted in a decrease in periphyton populations equal to that where sedimentation rates were relatively high.

Production varied significantly at 4 and 30 cm in clear water Empire Creek during two sampling periods (Table 6). These differences were only between 0.7 and 4.5 percent (Table 7), however, and were detectable only because of a very small variance within the replicate slides. Reductions in chlorophyll concentrations with depth were highly significant during all 1977 sampling periods on Little Balsam Creek, but 1976 samples demonstrated either no difference or increased production with depth (Table 7). This anomaly was due partially to different placement of the periphyton samplers. The 1977 sets were in shaded areas while samplers were in fairly open areas in 1976. The diatoms, which comprise the algal periphyton in these streams, are adapted to fairly low light intensities, and decreased production often occurs if light intensities are too high (33). Significant reductions in production were recorded at 30 cm during all periods except one at the two Skunk Creek sampling sites.

Reduction in standing crop of periphyton with depth appears to be as great on the relatively clear-water Little Balsam Creek as the turbid Skunk Creek sites. Turbidity at levels encountered in Skunk Creek during this study apparently does not have a great effect on production at 30 cm. Esti-

Table 6. Effect of depth (4 vs. 30 cm) and angle of orientation (horizontal vs. vertical) on chlorophyll a expressed as F-values for two-way analyses of variance. The AOV were performed independently for each site within each time period.

Period	Empire Creek			Little Balsam Creek			Skunk Creek (Station 11)			Skunk Creek (Station 13)		
	D[1]	A[2]	DA[3]	D[1]	A[2]	DA[3]	D[1]	A[2]	DA[3]	D[1]	A[2]	DA[3]
9/3/76	---	---	---	20.62++	10.6++	39.18++	---	---	---		undetectable	
10/26/76		undetectable		.002	2.19	1.9		undetectable			undetectable	
5/31/77	0.37	34.96++	15.79++	68.75++	101.08++	40.29++	44.15++	70.26++	1.29	---	---	---
6/20/77	3.49	37.7++	0.59	45.6++	83.87++	36.01++	104.38++	655.41++	.058	98.62++	134.43++	29.98++
7/12/77	7.27+	2.34	6.89+	2138.0++	770.0++	310.0++	47.3++	14.52++	0.41	98.6++	430.0++	21.42++
8/1/77	11.73++	1.98	0.25	28.45++	46.9++	22.73++	24.59++	52.77++	6.34+	29.97++	170.68++	37.29++
8/22/77	---	---	---	36.99++	96.68++	23.31++	32.02++	138.0++	2.14	1.22	74.9++	12.88++

\+ Significant at the 0.05 alpha level.

++ Significant at the 0.01 alpha level.

[1] D = Depth

[2] A = Angle of orientation.

[3] DA = Depth x angle interaction.

Table 7. Chlorophyll a/m^2 on glass slides in Empire, Little Balsam and Skunk Creeks at two depths in horizontal and vertical positions for seven periods between September 1976 and August 1977. Values are the average of four replicate slides at each treatment combination.

		Empire Creek (Site 10)		Little Balsam Creek (Site 8)		Skunk Creek (Site 11)		Skunk Creek (Site 13)	
		Horiz.	Vert.	Horiz.	Vert.	Horiz.	Vert.	Horiz.	Vert.
9/3/76	4 cm	---	---	32.42	24.17	undetectable		undetectable	
	30 cm	---	---	27.69	53.88	undetectable		undetectable	
10/26/76	4 cm	undetectable		6.1	2.55	undetectable		undetectable	
	30 cm	undetectable		4.34	4.21	undetectable		undetectable	
5/31/77	4 cm	1.01	4.32	2.55	14.72	4.57	6.98	3.01	11.63
	30 cm	2.14	2.79	1.11	3.86	3.18	4.99	---	---
6/20/77	4 cm	0.27	0.87	0.75	12.90	12.97	33.27	5.1	23.67
	30 cm	.06	0.71	0.15	2.68	5.13	25.06	0.25	6.91
7/12/77	4 cm	23.71	24.58	32.41	46.64	57.38	72.61	32.97	76.64
	30 cm	23.54	23.46	23.52	26.67	36.04	46.88	23.84	51.57
8/1/77	4 cm	23.87	24.04	26.36	45.04	28.99	39.47	24.47	43.76
	30 cm	23.62	23.70	25.66	28.97	26.37	31.46	23.83	31.72
8/22/77	4 cm	24.01	25.33	26.4	44.24	27.1	33.10	25.95	27.35
	30 cm	---	---	24.88	30.96	25.20	29.87	24.67	28.03

mates of total annual production derived from measuring the areas under the curves in Figure 5 show significantly lower levels only in Empire Creek (Table 8), with slightly depressed levels at site 13 on Skunk Creek. Water temperature and incident light (Empire Creek has the lowest mean annual temperature and densest tree canopy) therefore have greater effects than the turbidity and sedimentation encountered in this study.

Table 8. Relativized values for total annual production on glass slides at two depths and two angles of orientation on Empire, Little Balsam and Skunk Creeks.

Depth (cm)	Empire Creek (Site 10)		Little Balsam Creek (Site 8)		Skunk Creek (Site 11)		Skunk Creek (Site 13)	
	Horiz.	Vert.	Horiz.	Vert.	Horiz.	Vert.	Horiz.	Vert.
4	0.39	0.43	0.61	1.00	0.65	0.95	0.46	0.94
30	0.37	0.37	0.55	0.78	0.48	0.78	0.39	0.63

A greater reduction in standing crop with depth on the vertical slides than on the horizontal slides resulted in significant interactions between depth and angle of orientation in the two-way analysis of variance for Little Balsam Creek and site 13 on Skunk Creek (Table 6). Two out of four interactions were significant on Empire Creek and only one out of five at site 11 on Skunk Creek. This might be expected as light would be more limited with a vertical orientation, thus reducing production. The absence of this interaction at site 11 on Skunk Creek resulted from a fairly equal decrease in production on both horizontal and vertical slides. The reasons for this different type of light response are not readily apparent.

Microorganisms

The natural stream ecosystem is driven primarily by organic inputs from terrestrial sources, with primary production generally assuming a relatively minor role as an organic source. The stream insects which eat the leaves or filter particulate organics from the water derive minimal nutritional value from the organic source itself, but depend primarily on the bacterial and fungal populations which decompose the organics. Nitrogen fixing bacteria, which compose a portion of the periphyton, provide the primary nutrition for grazing insects (34). Microorganisms are thus the basic food source for stream macroinvertebrates as well as the agents which make streams such efficient processors of terrestrial organics.

Microorganisms which inhabit streams include terrestrial bacteria washed into the stream, microorganisms that are able to sustain life on a low level of organics, and microorganisms that need a substrate for their proliferation (35). Terrestrial bacteria assume a relatively minor role as very few survive long in water. The microbial population is influenced by factors such as the concentration of dissolved nutrients, particularily phosphates, the availability of organic nitrogen (for types unable to utilize inorganic nitrogen), and the presence of particulate matter in the water column (36).

Monitoring of microbial populations was begun in this study when it was noted that the macroinvertebrate population in the turbid stream equaled or exceeded those in clear-water streams. Clay particles have been cited as a suitable substrate for microorganisms as they absorb and concentrate organics and nutrients (37, 38, 39). Microbial growth is therefore possible in this microenvironment where enzymes and nutrients may be so dilute as to be limiting in the water column. It was thought that the clays and associated microfauna could be enhancing macroinvertebrate populations by serving as a food source in turbid streams. In addition to assisting in developing understanding of the importance of turbidity to the trophic stature, monitoring of microorganisms served to determine whether human or animal wastes were entering these streams.

Average bacterial counts for 1977 and 1978 (Table 9) were higher in turbid Skunk Creek (site 13) than in the clearwater Little Balsam (site 8) and Empire (site 10) Creeks. Although many other physical, climatic and chemical factors influence microbial populations, a positive trend with turbidity exists. The fungi population exhibits the opposite trend with turbidity, with lower numbers in Skunk Creek than in Little Balsam and Elim Creeks.

The trends which appear in between site comparisons of bacterial and fungal counts are not apparent for within stream counts. No consistent correlations were found between turbidity and microbial counts at given sites. Factors associated with rainfall and increasing turbidities caused greatly fluctuating populations and obscured relationships. After rainfalls there was a temporary rise in the bacterial populations, apparently due to an influx of terrestrial microbes and to increased nutrients and dissolved or particulate organics which trigger a proliferation of native stream bacteria. The population drops rapidly as most terrestrial microorganisms die and the organics are depleted.

Although higher bacterial populations were suggested in turbid sites, the results reveal no startling differences due to turbidity. However, bias associated with the enumeration technique may mask more significant differences. The membrane filter technique used for enumeration allowed only one colony to be formed per clay particle, even if several bacteria were present on each particle.

Table 9. Turbidity, bacteria and fungi range and means (in parentheses) in Little Balsam Creek (site 8), Empire Creek (site 9), and Skunk Creek (site 13) during 1977 and 1978.

Site	Turbidity (FTU)	Total Bacteria (No./ml)	Fecal Coliform (No./100 ml)	Fungi (No./ml)
Little Balsam (Site 8)				
1977	3-22 (5.45)	102-3200 (1058.4)	0-114 (29.8)	13-6500 (1178.3)
1978	4-25 (9.9)	90-2740 (762.9)	0-18 (6.9)	14-310 (84.0)
Empire (Site 10)				
1977	2-6 (2.8)	400-1280 (833.0)	0-134 (36.3)	5-5900 (907.6)
1978	3-25 (8.6)	50-1400 (542.9)	0-7 (3.6)	12-505 (138.3)
Skunk (Site 13)				
1977	10-66 (29.1)	520-8000 (2205)	0-1030 (274.5)	33-650 (188.4)
1978	22-220 (82.6)	230-9100 (2702.9)	0-325 (119.6)	32-325 (95.6)

The fact that clay particles may concentrate bacteria and fungi is potentially benefical to macroinvertebrates as they are more readily available to the large number of insects which feed by filtering particles from the water column.

The major groups of bacteria found in Little Balsam, Empire, and Skunk Creeks did not differ appreciably between sites (Table 10). Flavobacterium, which was found at all sites, is very common in aquatic systems. Bacillus, which was abundant during periods of high discharge and turbidity in Skunk Creek, is commonly found in soils and reflects the higher rates of erosion prevalent in the Skunk Creek basin.

Bacillus was not common during periods of low-flow, indicating poor survival in water.

Table 10. Major groups of bacteria in Little Balsam, Empire and Skunk Creeks in order of magnitude of occurence.

Little Balsam Creek (site 8)	Empire Creek (site 10)	Skunk Creek (site 13)
Proteus*	Proteus	Proteus
Flavobacterium*	Micrococcaceae**	Bacillus*
Micrococcaceae**	Flavobacterium	Flavobacterium
		Micrococcaceae

* Genus
**Family

Macroinvertebrates

Field Studies

The effect of heavy sedimentation on stream macroinvertebrates has been shown by some authors to affect the numbers and biomass of organisms with very little associated change in species composition (17, 18). Herbert et al. (18) found the bottom fauna to be 3.3 times more numerous where heavy clay sediment was not polluting the stream. No changes in species composition were noted. Turbidity levels of the polluted stream in that study varied from 900-7500 ppm, a minimum of 6 times the high levels normally found in the Nemadji Basin. Other authors, including studies cited by Cordone and Kelly (15) and Chutter (40) and studies by King and Ball (41) and Nuttal and Bielby (42) found significant changes in the composition of the bottom fauna with increased siltation.

The effect of sedimentation on the benthic fauna seems to be manifested primarily through changes in the character of the stream substrate. Complete inundation of pools and riffles by silt and sand, as has occurred in several studies, would have obvious effects on faunal composition through formation of a monotypic environment. It is also a very unstable environment, unsuitable for trapping detritus and prone to be flushed away during floods. When a rocky stream substrate is not completely covered, reduction in the benthic population may occur through elimination of interstitial space. The preference (or greater population size) of insects has been found to be large rubble>medium rubble>gravel>bedrock>sand (43, 44, 45). Generally, the more interstitial space, the higher the preference for the substrate.

Rates of deposition in areas of the Nemadji River Basin where most of the erosional products are clay are not great enough to inundate the rocky substrate. The most dramatic effects of erosion are in reaches of the river where large quantities of sand are contributed to the bed load. The substrate in these areas is extremely unstable and harbors the lowest benthic populations in the system (site 4, Figure 6). Only the biting midges, Ceratopogonidae, seem to be adapted to this shifting sand. In more upstream areas of the Nemadji and in the tributaries where little sand is contributed to the bed load a pool-riffle continuum is formed with stable substrates and resultant increases in benthic populations.

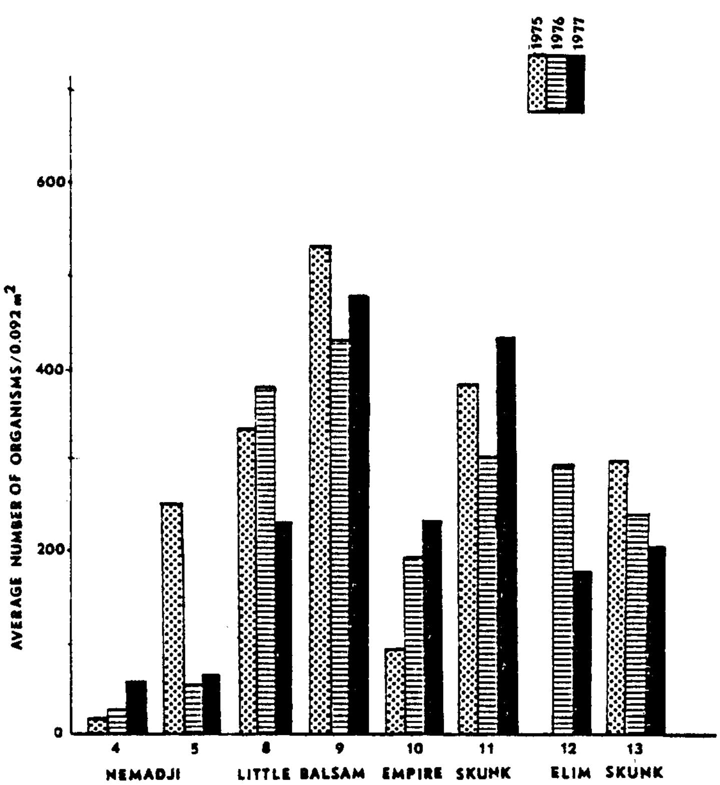

Figure 6. Average number of organisms in Surber samples from sites on the Nemadji River and tributaries in 1975, 1976, and 1977.

Streams have been classified as rich, average, and poor on the basis of weight of benthic organisms per unit area (46) and number of organisms per unit area (47). Applying Madsen's classification (47), most Nemadji system sites would be classified as 'rich' (>200 organisms/0.092 m^2) (Table 11). The exceptions are site 4 on the Nemadji River, which was always 'poor' and sites 5 (Nemadji River), 10 (Empire Creek), and 12 (Elim Creek), which varied between rich and poor (Table 11).

Table 11. Stream classification on the basis of density of macroinvertebrates (Madsen, 1935). Sites are classified as "rich" if densites exceed 200/ 0.092 m^2, "average" if density > 100 but < 200/ 0.092 m^2, and "poor" if densities < 100/0.092 m^2. Densities are yearly averages for combined pool and riffle benthic samples (see Figure 6).

S I T E		Y E A R		
Description	No.	1975	1976	1977
Nemadji R. (Central Portion)	4	Poor	Poor	Poor
Nemadji R. (Central Portion)	5	Rich	Poor	Poor
Little Balsam Cr. (Near Mouth)	8	Rich	Rich	Rich
Little Balsam Cr. (Headwaters)	9	Rich	Rich	Rich
Empire Cr.	10	Poor	Average	Rich
Skunk Cr. (Above Elim)	11	Rich	Rich	Rich
Elim Cr.	12	----	Rich	Average
Skunk Cr. (Below Elim)	13	Rich	Rich	Rich

With the exception of Elim Creek (site 12), the only sites which were not consistently classified as rich were those with small or consolidated substrate. The turbid tributaries with stable substrates support as large a benthic population as do those streams with minimal erosion and high water clarity (Figure 6). The lowest populations, in fact, occur in Empire Creek, with the exception of the Nemadji River sites with unstable substrate. Empire Creek has the lowest mean annual turbidities and no clay in the watershed. Small gravel predominates in the riffle areas as opposed to rubble and large gravel at sites with higher macroinvertebrate densities. The lack of the larger substrates does not allow maintenance of a large standing crop of macroinvertebrates. The higest average number of benthic organisms (site 9 on Little Balsam Creek) is in an area with an extremely stable discharge and rubble in both the pools and riffles.

The importance of available substrate in dictating standing crop of macroinvertebrates is further illustrated by the high biomass generally found on the Hester Dendy samplers at sites 4 and 5 on the Nemadji River (Figure 7). This contrasts with biomass in benthic samples (Figure 8). The high biomass values are a result of both the types of insects which occur and the relative attractiveness of the substrates. The large stonefly, *Pteronarcys dorsata*, is common in the Nemadji River and rare or absent at other sites. It is easily attracted by these artificial substrate samplers, and the presence of one or two stoneflies is enough to greatly increase total biomass.

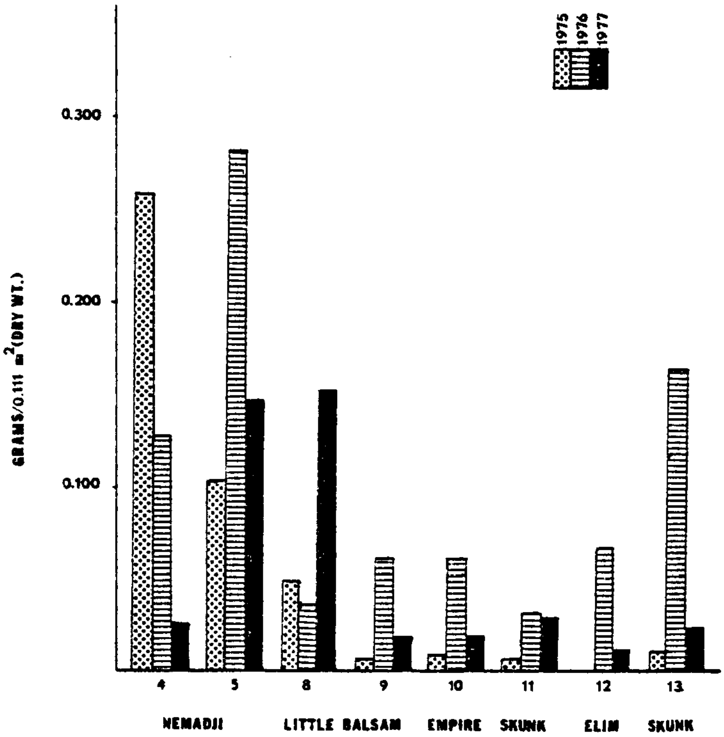

Figure 7. Average macroinvertebrate biomass (gms. dry wt.) on Hester Dendy samplers (0.11 m^2) from sites on the Nemadji River and tributaries in 1975, 1976, and 1977.

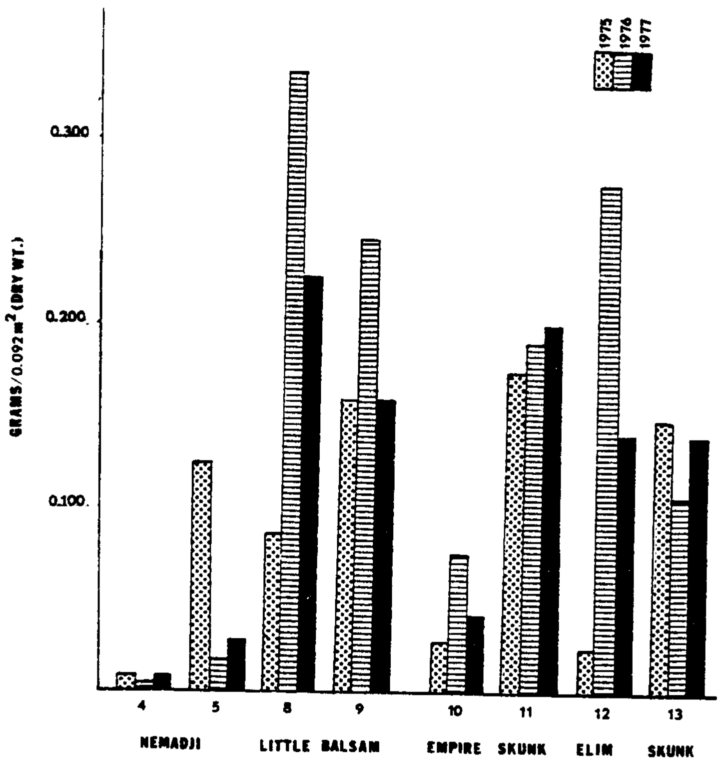

Figure 8. Average macroinvertebrate biomass (gms. dry wt.) in Surber samples (0.092 m^2) from sites on the Nemadji River and tributaries in 1975, 1976, and 1977.

There is also evidence that these multiplate samplers are more attractive and more heavily colonized where the natural substrate is fairly hostile as in the drifting sand characterizing site 4. Correlation of the Shannon-Weaver diversity indices between benthic and artificial substrate samplers at all sites for autumn 1977 yielded a correlation coefficient of -0.838 ($n = 7$, $P < 0.05$). This would indicate an active selection of the artificial substrate when available substrate was unattractive or uninhabitable, and a rejection if a suitable natural substrate was available. Consideration of only artificial substrate samplers may therefore not reflect the true macroinvertebrate population but rather use of the provided substrate by opportunistic individuals from the stream drift. Similar results were found with artificial substrate samplers by Wene and Wickliff (43). The correlation was not as strong when other sampling periods were included in the analysis.

Active recruitment of macroinvertebrates to artifical substrate was observed again when comparing the number of organisms and genera in the sandy substrate with the Hester Dendy samples and Surber sample from detritus at site 4

(Table 12). Mid-channel sand samples contained very few genera or numbers of invertebrates. Detritus samples contained many more genera and a large number of individuals. Hester Dendy samples, while intermediate in total number of organisms, attracted a large number of genera, further illustrating the effect of substrate conditions.

Table 12. Average number of organisms and genera in Surber samples from detritus areas, mid-channel sand substrate, and Hester Dendy samplers at site 4 in the Nemadji River.

Sample type	No. of genera	No. of organisms
Detritus	17.0	115.0
Mid-channel	4.3	18.5
Hester Dendy	26.0	87.5

The total number of taxa (generic level) occurring at the various sites is also insensitive to clay sedimentation (Figure 9). Again, only the Nemadji River sites with unstable sand substrates demonstrate a significant decrease.

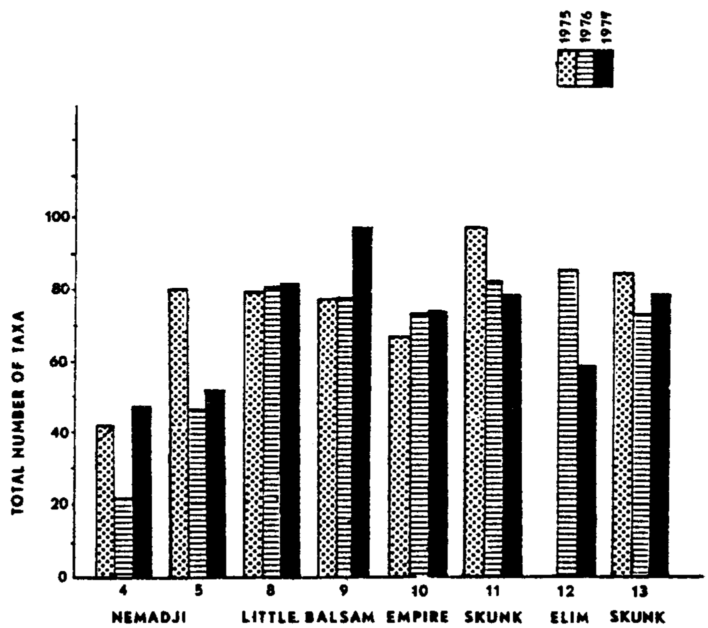

Figure 9. Total number of taxa encountered in Surber samples from sites on the Nemadji River and tributaries in 1975, 1976, and 1977.

With the lack of responsiveness in both total number of organisms and number of taxa, it is not surprising that species diversity does not change in relation to existing levels of turbidity or sedimentation (Figure 10). The differences which were formerly apparent in total numbers and number of taxa in site 4 on the Nemadji River are, in fact, obscured. The sandy substrate at this site is not an environment which limits survival in so much as it prevents occupation. No species dominates this area, resulting in occupation by many genera in fairly low numbers and a relatively high species diversity. Species diversity is thus a very poor index of the effects of turbidity and sedimentation under conditions encountered in this study.

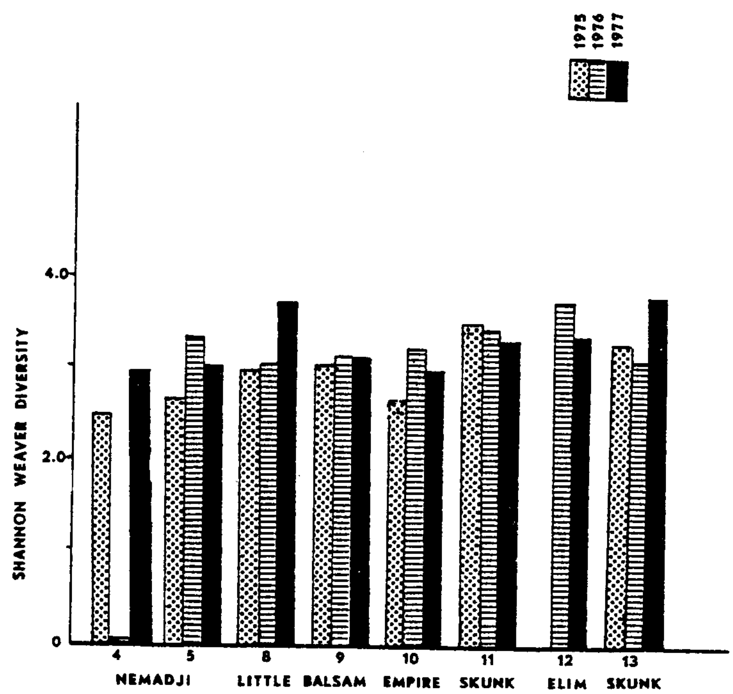

Figure 10. Shannon Weaver Diversity Indices from benthic samples from sites on the Nemadji River and tributaries in 1975, 1976, and 1977.

The possibilities of an increased microbial fauna associated with suspended clay particles and reduced primary production in the turbid streams (which did not prove to be true) were felt to offer the potential to affect the trophic structure of the insects. All genera were therefore assigned to a functional group according to Merrit and Cummins (48) or Hynes (30) (Appendix G provides a complete list of macroinvertebrates and assigned group). Some difficulties were encountered as many of the insects are opportunistic and can readily switch from one mode of feeding to another. The lumping of grazers, scrapers, gatherers, and collectors into one group (collectors) eliminated much of this problem. An exception was Palpomyia (Ceratopogonidae) which is classified as a carnivore or a collector. It was classified as a predator for this exercise (Appendix G).

Consideration of functional groups of insects by site did not demonstrate any differences in the relative number of each group which could be related to turbidity or sedimentation (Table 13). The herbivore (i.e. shredders, filterers, and collectors) to carnivore ratios did not demonstrate any trends between clear water (sites 8, 9, and 10) and turbid water (sites 5, 11, 12, 13) streams. The disproportionately high number of carnivores at site 4 was a result of classifying Palpomyia, the dominant organism, as a carnivore. The only other obvious differences in composition are the reduced number of filterers at sites 4, 10, and 12 and fewer shredders at sites 4, 11, 12, and 13. The low number of filterers is related primarily to the substrate type. Hydropsychidae (Trichoptera) compose the largest portion of this group, and they require large rock or rubble which does not occur in sites 4 and 10. Site 12 has suitable substrate but is intermittant and does not seem to be rapidly recolonized by this group. The shredders are composed primarily of stoneflies (Plecoptera). The reduced numbers at sites 4, 5, 11, 12, and 13 (all of the turbid sites) would seem to indicate that this group is inhibited by turbidity and sedimentation. No genera occurring at clear-water sites were absent from the turbid sites, however, and stoneflies are extremely sensitive to high water temperatures (30). The higher average temperatures in the turbid sites could therefore effect this change in total numbers. The clear water sites (8, 9, and 10) have superior aquifers and maintain much cooler temperatures through the summer months (Appendix A).

The taxonomic composition of the turbid and clear water sites differed slightly, but no invertebrates seemed to be hampered by existing levels of turbidity or sedimentation. At the ordinal level, there is a distinct reduction in the number of Plecoptera (stoneflies), (Table 14), but this was most likely due to temperature, as was previously discussed. The mayflies (Ephemeroptera), generally considered one of the most sensitive orders of insects for pollution studies, showed significantly greater population densities in turbid Skunk Creek than in the clear-water tributaries. No genera seemed to be hindered by turbid or silty conditions, but silt-loving genera such as Caenis sp., Hexagenia sp., and Ephemera sp. increased significantly. The family Heptageniidae and Isonychia sp. also increased in numbers.

Oligochaetes are one of the most sensitive indicators of silt in the substrate. The largest numbers occurred in the lower reaches of the Little Balsam where small quantities of clay and silt are found in the predominantly sand substrate of the pools. The relative numbers of oligochaetes remained low at all times. Oligochaetes represented 1% or less of the benthos in areas with no clays in the sediment

Table 13. Average number of predators, shredders, filterers, and collectors/0.092 m^2 with percent composition, total number of taxa in each group, and herbivore to carnivore ratios at 8 sites in the Nemadji River system. Estimates are based upon Surber samples collected during 1975-1977.

	SITE NO.															
	4		5		8		9		10		11		12		13	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Carnivores	12.3	43.6	12.0	11.7	19.3	7.2	47.6	11.3	24.3	12.8	25.6	7.6	21.1	9.5	20.7	9.7
# taxa	13		21		25		29		25		28		23		27	
Shredders	0.2	0.5	1.7	1.6	20.0	7.5	56.9	13.5	27.6	14.6	10.5	3.1	2.1	1.0	4.2	2.3
# taxa	5		6		14		15		14		13		11		13	
Filterers	1.2	4.4	45.8	44.5	91.5	34.1	138.5	33.0	29.4	15.5	95.1	28.2	27.2	12.2	54.7	25.8
# taxa	5		8		7		9		7		8		7		9	
Collectors	14.5	51.5	43.4	42.2	137.8	51.3	177.3	42.2	108.3	57.1	206.2	61.1	172.4	77.3	131.8	62.2
# taxa	45		47		49		46		45		59		45		50	
Herbivore/ Carnivore	1.3		7.6		12.9		7.8		6.8		12.2		9.6		9.2	

Table 14. Percent composition in benthic samples of major groups of organisms for all samples collected during 1975-1977. Chironomidae is listed separately from other Dipterans.

	Nemadji		Little Balsam		Empire	Skunk	Elim	Skunk
	4	5	8	9	10	11	12	13
Plecoptera	1.12	3.05	7.32	14.16	15.18	3.23	4.50	2.22
Ephemeroptera	7.96	16.20	8.98	8.77	6.09	21.18	22.68	11.82
Trichoptera	0.28	38.90	39.46	19.64	3.24	18.54	8.93	24.10
Coleoptera	0.50	4.23	0.62	0.32	0.13	15.70	5.65	16.27
Diptera								
Chironomidae	47.70	27.75	31.54	36.73	55.79	26.51	53.36	34.45
Other	38.79	7.04	6.81	18.83	18.74	9.47	6.34	6.20
Megaloptera	-----	-----	-----	0.18	0.34	0.02	0.08	0.04
Odonata	0.06	-----	0.02	-----	-----	0.17	0.06	0.03
Hemiptera	0.11	-----	-----	0.01	-----	0.17	0.06	0.03
Oligochaeta	3.25	2.70	5.07	1.00	0.27	3.99	2.15	3.17
Nematoda	0.02	0.03	0.02	-----	0.04	0.08	0.06	0.16
Hydracarina	-----	0.03	0.14	0.19	0.07	0.31	0.08	1.22
Limpets	-----	0.03	0.02	-----	0.06	0.38	0.06	0.18
Hydra	-----	0.02	-----	-----	-----	-----	-----	-----
Hirundinea	-----	-----	0.02	-----	-----	0.06	0.02	0.02
Sphaeridae	-----	-----	-----	0.12	0.03	0.26	0.02	0.10

while they comprised 2.5-5.0% of the samples from areas where red clay erosion was occurring.

The beetle larvae, *Optioservus* sp., is perhaps the best indicator for levels of silt which are detrimental to spawning success of the salmonids which require a free flow of water through the rocky riffles. *Optioservus* sp., which represent most of the Coleoptera in Table 14, is found almost entirely in riffle areas and occurs in significant numbers only where there is silt in the interstitial spaces of the riffles. *Optioservus* is a major portion of the benthos in Skunk Creek and occurs in significant numbers in the riffle areas of site 5 on the Nemadji River (Table 14) where there are substantial quantities of silt. It occurs infrequently in those sites occupied by trout and the Nemadji River site 4 where sand predominates in the substrate.

Laboratory Studies

Laboratory analysis of the levels of turbidity which affect activity and respiration in the stonefly, *Pteronarcys dorsata*, demonstrated that turbidities must be much higher than those encountered in the Nemadji River system to elicit any response, at least for the test organism. At the nominal turbidity levels of 2.5, 100, 250, 500 and 1000 FTU, respiration rates were not significantly higher except at the 1000 FTU level (Table 15).

Table 15. Mean respiration rates of *Pteronarcys dorsata* with levels of significance for comparisons with Control (2.5 FTU).

	Turbidity Level (FTU)				
	2.5	100	250	500	1000
µl O_2/g dry wt/hr	338.95	275.71	407.21	295.35	709.41[a]

[a]Significantly different at .01.

The similarity in respiration rates at all but the highest concentration of suspended solids suggests a threshold effect. There was a noticeable amount of clay covering the nymphs in the 1000 FTU experiment (highest concentration). At no other concentration was the covering apparent. The covering of clay extended over nearly the entire body of each animal, including the gills. The increased respiration rate was most likely due to the movements of the animal to rid itself of this covering. Respiration rates of the nymphs during the 2.5 to 500 FTU experiments were similar to those of *P. californica* (49).

The stonefly numphs exhibited different activity levels at the nominal turbidities of 1.5, 25, 60, and 150 FTU at the three current velocities. There were no significant trends at 1.6 cm/sec (Figure 11) (P = .54). Activity increased with turbidity at 0.8 cm sec (Figure 12) but was not significant at the 95% confidence level (P = .059). There was a significant increase in activity at 0.4 cm/sec (P = .03) (Figure 13). Activity did not increase appreciably until turbidities reached the highest level (150 FTU). Application of a Kruskal-Wallis test (51) showed a significant difference in activity between the experiments at the different water velocities [P = 0.0001].

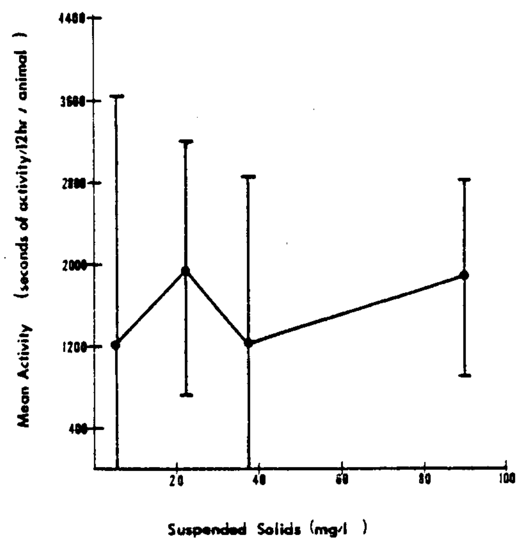

Figure 11. Mean activity of P. dorsata nymphs at turbidities of 1.5, 25, 60, and 150 FTU at the 1.6 cm/sec flow rate.

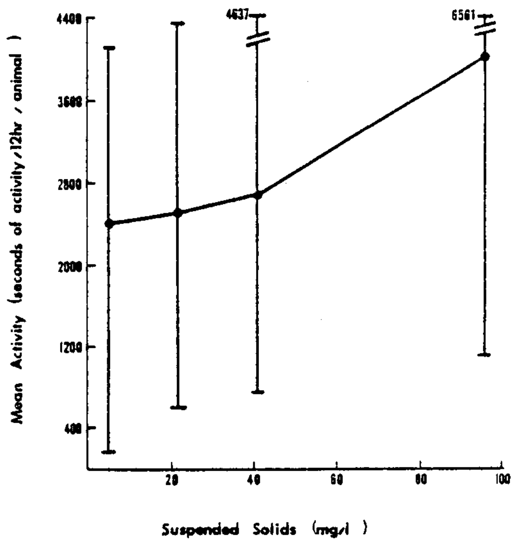

Figure 12. Mean activity of P. dorsata nymphs at turbidities of 1.5, 25, 60, and 150 FTU at the 0.8 cm/sec flow rate.

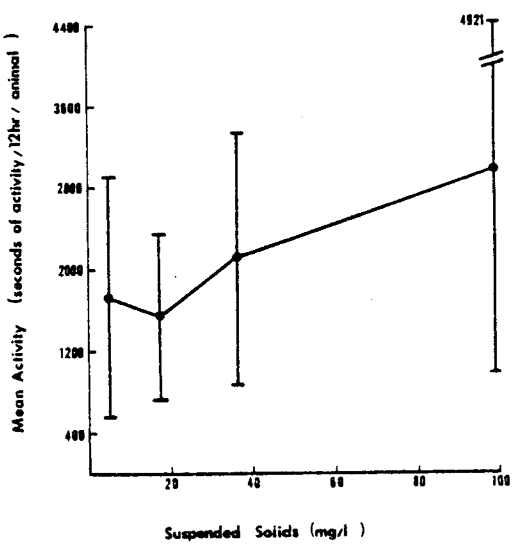

Figure 13. Mean activity of P. dorsata nymphs at turbidities of 1.5, 25, 60, and 150 FTU at the 0.4 cm/sec flow rate.

The results of the activity experiments suggest that the water flow rate and the concentration of suspended solids interact to affect the activity of P. dorsata nymphs. Activity increased among treatment combinations as the suspended solid concentration increased and the velocity decreased. The increased response to turbidity at lower flow rates is the reverse of what would be expected if the effect of suspended material was related primarily to abrasion, assuming increased abrasion would increase and not decrease activity.

The reason for the increased activity of the nymphs is most likely behavioral. Behavioral mechanisms that are plausible include enhanced activity due to reduction of light by suspended solids, increased activity to remove any clays settling on the body, and increased activity in an effort to avoid a silted substrate. Activity of stream dwelling insects is known to be linked to very low light intensity (52, 53). Because of the abrupt light-to-dark change as the laboratory lights turned on and off and the extreme darkness of the 12 hr night period in these experiments, the effect of increased activity with decreased light due to suspended solids would be evident only during the lighted period. However, the small dimensions of the glass troughs allowed light to penetrate to the depth of the nymphs at all suspended solids levels. Therefore, increased activity due to light reduction is unlikely in this experiment. No significant difference was found between the daytime activity in the control versus turbid water troughs at flow rates of 0.8 cm/sec ($P = 0.56$) or 0.4 cm/sec ($P = 0.36$) using a Wilcoxon Two-Sample test.

An alternative explanation is that the clay settling on the animals may have irritated them or reduced their ability to exchange gases through the gills and body integument. Since the ventro-lateral position of the gills of the nymphs protects them from becoming silt-covered, the latter explanation seems unlikely. A general irritational effect cannot, however, be ruled out.

It is known that some species of stream dwelling insects avoid substrates that are covered with silt (54, 55, 56, 57). The settled clay may have influenced the results of these experiments, by increasing activity as the nymphs moved about in search of more suitable substrate.

In addition, current speed is known to affect the distribution of some aquatic insects (40, 57, 58), Pteronarcys dorsata was normally collected in areas of very low flow rate, namely in leaf packs and in debris near the edges of the Nemadji River. If one assumes an optimum, low, current velocity for P. dorsata and a hierarchy of effects of current velocity and settled solids, the decreased activity at higher flow rates is more easily explained. Since all experiments at the same turbidity had comparable clay deposition rates

(Table 16), at the 1.6 cm/sec flow rate the effect of current on the activity of the nymphs may have been more important than the reaction of the nymphs to the settled clay. The low activity at all suspended solids levels indicates that at flow rates that are abnormally high for their microhabitat the nymphs lower their activity. Lowering the activity would lessen the chance of being carried away by the current. The generally higher activity levels in the 0.8 cm/sec as compared with the 0.4 cm/sec experiments can be explained by the combined effects of deposited sediment and current velocity. The 0.8 cm/sec flow rate was most likely above the optimum for this species, but below the threshold that reduced activity. In this case the activity of the nymphs was enhanced by both the flow rate (as they increased activity to seek a more suitable velocity) and deposited solids. At the 0.4 cm/sec flow rate, the velocity was nearer the optimum and there was a general decrease in activity. In this case, the settled clay affected the activity more than did the current velocity, resulting in a significant increase in activity at the highest turbidity level. Rabeni and Minshall (57) found that both current velocity and a thin silt covering on the substrate affected the distribution of many aquatic insects.

Table 16. Sediment deposition rates for the mean turbidities at each experimental flow rate during activity experiments with *P. dorsata*.

Turbidity levels (FTU)	Experimental Flow Rates (cm/sec) 1.6	0.8	0.4
	Sediment Deposition Rates ($mg/cm^2/sec$)		
150	1.5×10^{-6}	1.587×10^{-6}	1.631×10^{-6}
60	6.142×10^{-7}	6.708×10^{-7}	6.253×10^{-7}
25	3.758×10^{-7}	3.418×10^{-7}	3.429×10^{-7}
2.5	8.392×10^{-8}	8.608×10^{-8}	8.872×10^{-8}

Although the maximum suspended clay concentrations were different in the activity and respiration experiments (150 and 1000 FTU, respectively), the results support Hynes' (50) general statement that "There seems to be little evidence of any direct effect of suspended matter on animals . . .". The effects are those produced by the settling of suspended material, either onto the substrate or onto the animal. The experiments suggest that increased movement of the nymphs, evident as increased respiration and activity, is due to an irritational effect of clay settled onto the animal. In the activity experiments this reaction could have been augmented by movement to avoid a silted substrate.

The relation between suspended solids concentration, water velocity and activity of *P. dorsata* nymphs is complex. Activity tends to increase with increased suspended solids concentration, and is also influenced by water velocity. The increased activity of the nymphs as suspended solids concentration increased indicates irritation of the nymphs by settled clay or an avoidance reaction to a silted substrate. Water velocity increased activity when it was not at some optimum (here at approximately the 0.4 cm/sec flow rate). The increased activity observed in these experiments suggests that the nymphs would move from areas of siltation and non-optimum water velocity in nature. The presence of the nymphs in the Nemadji River suggests that the suspended solids concentrations are generally not high enough to cause loss of the species from the fauna. If suspended solids levels increased to levels similar to the highest used in these experiments (approximately 1000 FTU), some of the fauna could be eliminated.

Fish

Field Studies

Thirty-five species of fish were collected in the Nemadji watershed during this study. Appendix H identifies the species collected and their relative abundance by site. The Nemadji River and the turbid tributaries (Skunk and Elim Creeks) were dominated by the minnow (Cyprinidae) and sucker (Catostomidae) families. Clearwater tributaries (Empire and Little Balsam Creeks) were inhabited primarily by brown trout (*Salmo trutta*), brook trout, mottled sculpin (*Cottus bairdi*), and brook stickleback (*Culaea inconstans*). The small number of species in the cold headwaters resulted in low species diversity. Species diversity was lowest in the upper portion of Little Balsam Creek (site 9) and in Empire Creek (site 10; Table 17). More species occurred near the mouth of the Little Balsam (site 8) where minnows were common. Species diversity was correspondingly higher. The increased number of species was apparently the result of greater living space, slightly higher water temperatures, and the close proximity of warmer, more turbid Balsam Creek which supports a diverse minnow population.

Table 17. Shannon Weaver species diversity indices, total number of species, average number of fish/hec and fish biomass/hec in sites on the Nemadji River and Little Balsam, Empire, Skunk and Elim Creeks (see Appendix I for sampling period estimates from which averages were derived).

Site		Species diversity	No. species	Fish/ hec.	Kg/ hec.
1	Nemadji R. (near mouth)	2.91	13	---	---
4	Nemadji R. (central portion)	3.19[a]	20	1300[a]	19.4[a]
5	Nemadji R. (central portion)	3.05[a]	23	3287[a]	21.2[a]
8	Little Balsam Cr. (near mouth)	2.59	9	9252	70.5
9	Little Balsam Cr. (headwaters)	1.52	6	4087	46.0
10	Empire Cr.	1.32	4	7340	120.1
11	Skunk Cr. (above Elim)	2.69	9	8545	66.7
12	Elim Creek	2.31	8	13127	98.2
13	Skunk Cr. (below Elim)	3.00	14	7487	96.7

[a]does not include sucker spring spawning runs.

Species diversity was higher in the turbid warmwater streams than in the streams with low turbidity. The highest diversity was in site 4 on the Nemadji River. It was also characterized by the lowest standing crop of fish (Table 17). Suitable habitat was restricted to the very narrow river margins where roots and branches provided shelter and the only habitat other than relatively sterile drifting sand. The occurrence of many species, and absence of a dominant species, resulted in a high diversity value. Site 5 contained more species than any other site as it had a fairly diverse pool-riffle habitat which supported a variety of stream dwelling species as well as providing spawning habitat for Lake Superior species. Skunk and Elim Creeks, the other turbid sites, had fairly high diversity values due to the variety of minnows and other small fish common to these streams.

The species of fish which inhabited a given stream or site was dictated primarily by the stream origin and resultant water temperatures. The Nemadji River headwater streams are in both sandy and clay type soils. Those streams originating in sandy reaches have good aquifers and are generally cold-water trout streams. Those in areas dominated by clays have very poor aquifers and receive most of their discharge from surface runoff. These streams will either not support trout or are very poor trout waters due to marginally high water temperatures and unstable discharges. Of the study streams, Empire and Little Balsam Creeks originate in sandy areas. Skunk and Elim Creeks and that part of the main body of the Nemadji River sampled originate or flow primarily through clay soils and do not support viable populations of cold-water fish.

Differences in discharge and temperature made interpretation of differences in fish populations among the study streams difficult to relate directly to clay turbidity or sedimentation. The Nemadji River and turbid tributaries support fish populations dominated by minnows but no major predators. Three trout were found in three years of sampling Skunk Creek. A few migrant spawning brown trout and steelhead and a rare northern pike or rock bass composed the predator population in the Nemadji River with the exception of a large population of walleye during late spring and early summer in deeper reaches of the river close to Lake Superior. This lack of predators in the turbid streams is probably related more to channel form, temperature, and discharge than turbidity.

Lake trout have been shown to avoid turbid waters in Lake Superior (4) and it is possible that the waiting-watching-darting which typifies feeding behavior in stream-dwelling trout is hindered by turbid water. However, low discharges and marginal temperatures which characterize turbid streams in the Nemadji drainage are probably more inhibitory to trout habitation than turbidity. Herbert *et al.* (18) found no change in distribution of trout at turbidities up to 60 ppm (92 FTU). This turbidity is reached only during periods of high water in the Nemadji River System. Laboratory studies by the same group (59) demonstrated no effect on survival at turbidities less than 270 ppm (436 FTU). Even this is quite low compared to the results of other studies on the direct effects of turbidity. Wallen (60) found no direct effect on warmwater fish at 100,000 ppm (164,000 FTU). MacCrimmon (61) found no effect on survival of young Atlantic salmon in streams at 1150 JTU (approximately 1100 FTU). A review of the direct effects of suspended sediments on fish (15) suggests that levels which are directly harmful are far above those which reduce fish populations through the indirect effects of habitat alteration, destruction of the food supply, or impairment of reproductive success. Our studies in the Nemadji River watershed have demonstrated that none of these indirect effects occur except in areas where sand is the primary erosional product.

The limited overlap of fish species between clear and turbid water streams restricted specific comparisons of growth to creek chubs between the Nemadji River (avg. turb. = 51.5 FTU) and Skunk Creek (avg. turb. = 54.2 FTU) and brook trout between Empire (avg. turb. = 6.4 FTU) and Little Balsam (avg. turb. = 4.6 FTU) Creeks. Creek chubs, although occasionally collected in Little Balsam Creek, were present only seasonally when they migrated from Balsam Creek into which Little Balsam Creek flows. Age and growth data from Little Balsam creek chubs was therefore not reflective of conditions within the stream and was not considered in comparison with the turbid sites.

Results of the Nemadji River - Skunk Creek comparisons demonstrated a significantly higher growth rate ($P < 0.025$) for Skunk Creek creek chubs (Table 18). This is probably a result of the higher average temperature in Skunk Creek. Although these results might not be surprising in light of temperature differences, it does indicate that there are no detrimental effects due to slightly elevated turbidities. (Although average turbidities were similar, Skunk Creek maintains a higher low flow turbidity which was compensated in the Nemadji River by higher high water turbidities.)

Brown trout growth was calculated for fish captured in Little Balsam and Empire Creeks (Table 19). Comparison of growth rates between fish from these creeks cannot be made as sampled fish had completed only one year of growth in Empire Creek. Comparison of growth between Little Balsam Creek brown trout and brook trout showed brown trout grow faster in this stream. It appears that the same is true in Empire Creek but only the first years growth is known.

Table 18. Calculated and grand average calculated total lengths (mm) of creek chubs (*Semotilus atromaculatus*) captured in Nemadji River sites 4 and 5 and Skunk Creek sites 11 and 13. Fish captured during 1976 and 1977 were combined for analysis.

Nemadji River		Total Length (mm) at Age				
Age	Number of fish	1	2	3	4	5
V	1	44	64	91	121	140
IV	2	60	86	110	147	
III	8	40	60	82		
II	35	47	70			
I	21	45				
Grand Average Length		47	70	94	134	140

Skunk Creek		Total Length (mm) at Age				
Age	Number of fish	1	2	3	4	5
V	2	65	99	138	168	199
IV	8	58	84	112	137	
III	17	56	78	103		
IV	30	54	75			
I	23	53				
Grand Average Length		57	84	118	153	199

Table 19. Calculated and grand average calculated total lengths (mm) of brown trout (Salmo trutta) captured in Little Balsam Creek sites 8 and 9 and Empire Creek site 10. All fish were captured during 1976.

Little Balsam Creek

Age	Number of fish	Total Length (mm) at Age 1	2	3
III	2	118	175	240
II	6	93	145	
I	12	100		
Grand Average Length		104	160	240

Empire Creek

Age	Number of fish	Total Length (mm) at Age 1
I	12	100
Grand Average Length		100

Comparison of growth rates between Empire (site 10) and Little Balsam (site 9) Creek brook trout (Table 20) demonstrates better conditions for growth in Empire Creek. The importance of suitable discharge and cover for trout growth (Empire Creek has a higher discharge and undercut banks) is well illustrated by this comparison as trout grow faster despite very low macroinvertebrate populations in Empire Creek (Figure 6). Suitable habitat in Empire Creek resulted in greater population biomass than Little Balsam Creek (Table 17) as well as better growth rate.

The reliance of trout on water discharge as a dimension of space (by allowing food to come to them instead of actively seeking) makes them one of the best adapted predatory game fish for small streams or shallow rivers where little foraging space is available. Streams the size of Little Balsam and Empire Creeks would not provide adequate space for any other game species. The middle reaches of the Nemadji River, with widths exceeding 20 meters, are typified by shallow pools and no undercut banks. The lack of living space for large fish other than trout, water temperatures which are not tolerated by trout, and lack of winter refuge when ice forms on this shallow river combine to provide a habitat which is suitable only for year around residency of small fish species and as a seasonal spawning ground for some Lake Superior fish. Similar effects can be seen in Skunk Creek where the poor aquifers result in very low summer discharges which make the stream a series of warm pools. Neither stream velocities nor temperatures are suitable for trout.

Table 20. Calculated and grand average calculated total length (mm) of brook trout (*Salvelinus fontinalis*) captured in Little Balsam Creek sites 8 and 9 and Empire Creek site 10. All fish were captured during 1976 in Empire Creek. Fish from Little Balsam Creek were collected during 1976 and 1977.

Little Balsam Creek

Age	Number of fish	Total Length (mm) at Age 1	2	3
III	2	96	124	158
II	8	85	130	
I	24	93		
Grand Average Length		91	127	158

Empire Creek

Age	Number of fish	Total Length (mm) at Age 1	2
II	15	93	154
I	32	92	
Grand Average Length		92	154

The single most important factor regulating fish population size within the Nemadji River System is channel form. The species which inhabit different portions of the system are dictated primarily by water temperature and discharge, but physical characteristics of the channels which provide cover and depth are uniformly beneficial to all of these populations. Maximum standing crops and production for both warm and cold water fish are inevitably associated with habitat diversity (see reviews 62, 63). One of the most important components of habitat involved in the concept of "suitable living space" for fish is cover, which might be provided by water depth, overhanging banks, submerged rocks, logs, and other "snags". Suitable cover has been demonstrated to be the primary factor regulating population size of brown trout (64) and is similarly important for other species. Cover in the form of roots along channel banks harbored the largest concentrations of fish in both Skunk Creek (primarily minnows) and Little Balsam Creek (trout). The toes of the clay banks in these streams slump rather than form undercut banks, eliminating this excellent form of cover.

The influence of channel form and undercut banks on carrying capacity of the stream is well illustrated by a comparison of the two Little Balsam Creek sites and Empire Creek. These streams have similar discharges, water quality, and water temperatures but the sandy banks in Empire Creek are steep-sided and undercut. Banks in the lower Little Balsam (site 8) are clay and seldom undercut. Cover is primarily in the form of roots and logs. The upper Little Balsam (site 9) has a lower discharge but there are no clay soils. There is consequently more cover in the form of cut banks and rubble. Many authors have cited food supply as a limiting factor for trout populations (65, 66, 67). However, Empire Creek maintains a much higher population and biomass of trout than the lower Little Balsam despite extremely low standing crops of macroinvertebrates (Figure 6), the primary food source for stream dwelling salmonids. The small macroinvertebrate population is not a result of cropping by the trout populations, but the prevelance of small and consolidated gravel and rock as opposed to the larger rock and rubble in the riffle areas of Little Balsam Creek. Site 8 on Little Balsam Creek has the highest fish population density (Table 21), but the populations are variable and composed primarily of minnows (44.5%). Site 9 (Little Balsam Creek) and 10 (Empire Creek) have lower total numbers of fish but trout numbers per hectare are much higher (49 and 320 percent, respectively) as is biomass, including total fish biomass. Trout biomass in upper Little Balsam and Empire Creeks exceeds that in the lower Little Balsam Creek by 15 and 207 percent, respectively. The increased numbers of "desirable" and "catchable" fish can be attributed entirely to channel form, cover, and the resultant increase in "suitable living space."

A similar response can be seen in population numbers and biomass at sampling sites in the warmwater streams (Table 17). Site 4 on the Nemadji River, with the least habitat diversity, has the lowest average population density and biomass. As habitat diversity increases at site 5, biomass and population size increase. In the Skunk and Elim Creek stream complex, differences in these closely associated sites are again related to channel form. Sites 11 and 13 on Skunk Creek differ in pool size and available cover. Site 11 has relatively smaller pools and more bank cover. This results in more fish but a smaller biomass as the fish are generally smaller than those occupying the larger pools at site 13. Population densities are very high in Elim Creek (site 12), as is total biomass. Elim Creek is an intermittant stream and the highly fluctuating water levels minimize sediment accumulation,

Table 21. Population size (fish/hec) and biomass (kg/hec) for major fish groups in Little Balsam and Empire Creeks for sampling periods between October, 1975 and October, 1977. Biomass estimates appear immediately below population estimates.

Site	Family	10/75	5/76	6/76	8/76	9/76	10/77	Average
8	Salmonidae	3237	1153	754	1685	1685	399	1486
Little Balsam Cr.		80.4	20.4	29.2	12.9	75.7	3.6	37.0
	Catostomidae	3725	266	2439	0	0	0	1072
		17.6	8.9	128.2	0	0	0	25.8
	Cyprinidae	0	665	1552	7317	14900	266	4117
		0	10.2	3.6	36.9	21.6	3.3	12.6
	Other	133	266	887	2971	10820	399	2579
		0.6	3.3	17.2	7.1	10.8	2.0	6.8
9	Salmonidae	738	1066	3690	1969	3609	2215	2215
Little Balsam Cr.		3.9	55.7	67.5	13.0	72.4	43.0	42.6
	Catostomidae	164	0	0	0	0	0	27
		0.2	0	0	0	0	0	0.03
	Cyprinidae	0	0	0	0	0	0	
			0	0	0	0	0	
	Other	7299	902	902	328	574	1066	1845
		10.9	1.1	2.7	1.1	1.2	4.3	3.6
10	Salmonidae	4757	2870	4347	9268	13369	2871	6247
Empire Cr.		97.6	55.2	130.0	223.5	123.9	50.8	113.5
	Catostomidae	0	0	0	0	0	0	
		0	0	0	0	0	0	
	Cyprinidae	0	0	0	0	0	0	
		0	0	0	0	0	0	
	Other	1804	0	1886	820	984	1066	1093
		12.1	0	4.9	6.2	11.1	5.3	6.6

resulting in a large percentage of rubble in both the pools and the riffles. This results in diverse habitat which is rapidly inhabited by the smaller Skunk Creek fish when stable flows are maintained.

Cover is one of the most important factors in maintenance of large populations for all species complexes in the Nemadji River System. Cover limitations as a result of bank slumpage is the major red clay associated feature affecting aquatic life. Practices commonly associated with "river cleanup" such as stump and snag removal could reduce the best cover available in these streams. Snag removal will eliminate the cover provided by the snag as well as the pool which is generally formed behind the snag. The result is a reduction in living space for larger fish as a featureless sand or silt substrate is formed where a pool and cover previously existed. Similar consequences as a result of stream channelization, which generally results in a wide, shallow channel, are well documented (68). Practices which slow the rate of toe erosion of the banks may be beneficial in maintaining steeper banks and greater water depth which are forms of cover.

The major importance of the Nemadji River to fish is as a spawning ground for Lake Superior populations. Turbidity in the lower reaches and mouths of rivers has been cited as a potential deterrent to spawning runs of trout (32). However, significant spawning runs of steelhead occur in the Nemadji River during its most turbid periods. Trout traverse up to 100 km of river to spawn in headwater streams where clays are minimal in the sediments.

Fish reproduction in most of the Nemadji River proper is limited to those species which do not bury their eggs. The salmonids, which bury their eggs, require fairly high rates of water flow through a rocky substrate for selection as a spawning site (10, 11), survival of eggs, and emergence of fry (12, 13, 14). Natural rates of siltation in the Nemadji River are much too high for successful reproduction of these fish.

The warm and coolwater species which migrate from Lake Superior to utilize area streams and rivers for spawning include burbot (Lota lota), walleye (Stizostedion vitreum vitreum), rainbow smelt (Osmerus mordax), suckers (both Catostomus sp. and Moxostoma sp.) and shiners (Notropis antherinoides and N. cornutus). All of these fish broadcast their eggs over rocky areas where they settle and adhere to the substrate or find refuge in the interstitial spaces. Both field monitoring and laboratory bioassays were conducted to assess spawning success of these species (except shiners and burbot) in the Nemadji River System and the effect of turbidity and siltation on egg survival.

All species mentioned above except the walleye utilize the Nemadji River for spawning. Walleye have not been observed to spawn in the Nemadji River, although they do spawn in the adjacent Pokegama River which has similar levels of turbidity and siltation. It therefore seems likely that factors other than turbidity discourage use of the Nemadji by spawning walleye. Catches of walleye in the lower Nemadji indicate abundance is highest after spawning is completed in other streams and is corelated with migrations of emerald, and common shiners. Migrating shiners did not demonstrate the close association with cover as resident prey sized fish did and probably represented an available food resource which attracts walleye to the stream.

Spawning success of the major runs of smelt, longnose and white suckers, and silver and shorthead redhorse was monitored using daily drift net samples during the periods of hatch. All of these species drift passively back to the harbor and Lake Superior after hatching, enabling rough estimates of total hatch when stream discharge and drift densities are known.

Smelt and suckers (all four species) hatched successfully in the Nemadji River in both 1976 and 1977. Larval smelt production in 1976 was estimated at just 20,000,000 (Figure 14). The major portion of the smelt hatch was missed in 1977, but the tail of the curve indicated similar trends. Sucker production in 1977 was estimated in excess of 23,000,000 (Figure 15). Estimates in 1976 were not possible as fry were concentrated at the surface. Up to 2000 fry were captured in 15 minutes in the net with a mouth opening of 0.04 m^2. The only other species of fry captured is unidentified, but is probably a minnow (Cyprinidae). Numerical estimates of the unknown species were 590,000 and 1,900,000 in 1976 and 1977 respectively. Although some fry production may occur in clear water tributaries, the collection of viable eggs and emergent fry in the Nemadji River indicate that most production occurs within the turbid waters.

Resident stream fish also reproduced successfully in the clear and turbid water tributaries. Young-of-year brook trout, brown trout, mottled sculpins, and brook sticklebacks were found in Empire (site 10) and Little Balsam (sites 8 and 9) Creeks. Young-of-year rainbow trout were also captured on two occasions at site 9, indicating successful spawning by lake-run steelhead. Fish which were noted to spawn successfully in turbid Skunk Creek included white sucker, johnny darter, mottled sculpin, and creek chubs.

Laboratory Studies

Egg Survival Bioassay: Some survival of rainbow smelt eggs occurred at all treatment concentrations during the two

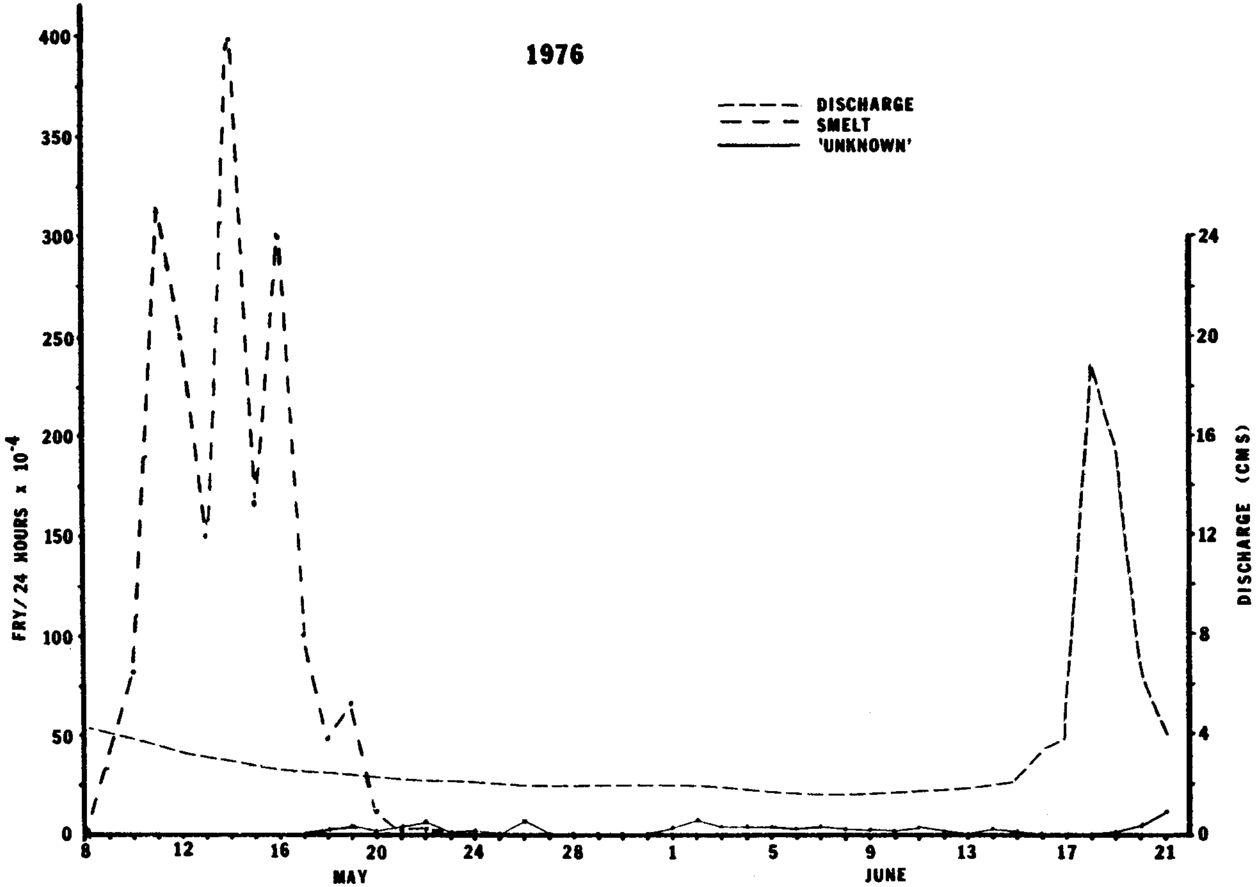

Figure 14. Daily numerical estimates of rainbow smelt and an unknown (probably a minnow) fry production in the Nemadji River, 1976. Estimates were made using fry drift density and stream discharge (cms).

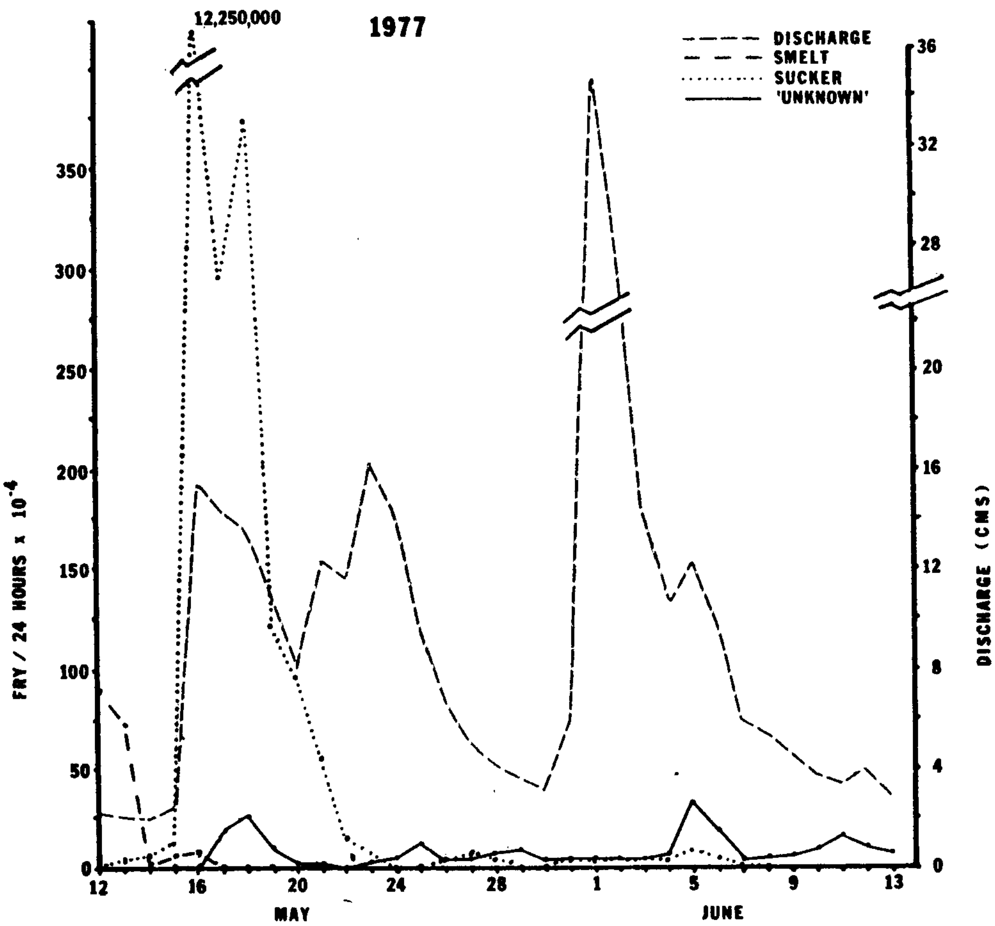

Figure 15. Daily numerical production estimates of suckers, rainbow smelt, and an unknown (probably a minnow) in the Nemadji River, during 1977. Estimates were based upon daily fry drift densities and stream discharge (cms).

years (1976-77) of study. No significant difference in survival was measured for this species during the 1976 test between the lowest (1.3 FTU) and highest (48.5 FTU) turbidity (Table 22, Figure 16). However, survival decreased significantly (P<0.01) during the 1977 tests when maximum turbidities were increased from 50 to 100 FTU. Survival was 25.6% in the control or nominal 0 FTU turbidity chamber and declined steadily to 3.8% in the highest turbidity treatment (100.9 FTU). There was a difference in survival of the eggs at the lowest treatment (0 FTU nominal) between the 1976 and 1977 stock (40.7 and 25.6%, respectively). The effect of stock differences on test results is not known.

Table 22. Survival of three species of fish eggs incubated at different turbidities during three spawning seasons. Survival is described as mean percent and (in parentheses) percentage range of fish eggs surviving to hatch.

Species of eggs incubated	Year	Nominal Turbidity (FTU)				
		0	10	25	50	100
Rainbow Smelt	1976	40.7 (32-57)	42.9 (30-57)	42.3 (33-50)	45.2 (36-74)	---
	1977[a]	25.6 (9-42)	---	18.8 (14-24)	9.5 (0-30)	3.8 (1-8)
Walleye	1976	47.2 (32-66)	47.2 (10-74)	29.5 (4-58)	29.5 (6-58)	---
	1977[a]	47.0 (41-52)	---	22.8 (21-26)	22.2 (9-40)	7.0 (1-20)
	1978	4.6 (0-14)	---	3.6 (0-8)	1.5 (0-4)	8.6 (0-18)
Longnose Sucker	1978	29.4 (0-44)	---	12.3 (0-26)	10.2 (0-40)	19.6 (2-38)

[a]Significant ($P<0.01$) reductions in survival due to treatments.

The effects of turbidity on walleye egg survival were tested during three years (1976-78). The 1976 and 1977 results (Table 22, Figure 16) were consistent with one another showing similar survivals at all the duplicated treatment exposures. Results of the 1976 test showed no difference between the nominal 0 and 10 FTU turbidities but did show reduced survival at all test concentrations above 10 FTU. However, this reduction in survival was not significant ($P > 0.10$). The 1977 test showed nearly the same results as the 1976 tests through the nominal 50 FTU treatment and showed further reduction in survival to 7.0% at the highest treatment (94.1 FTU). The difference was significant ($P < 0.01$). In 1978 survival was greatly reduced from the previous two years at all but the highest turbidity (100 FTU nominal). Eggs during this test became heavily infected with a fungal growth which resulted in mortalities of otherwise healthy eggs. Egg survival in 1978 was impacted more by this growth than the turbidity treatments.

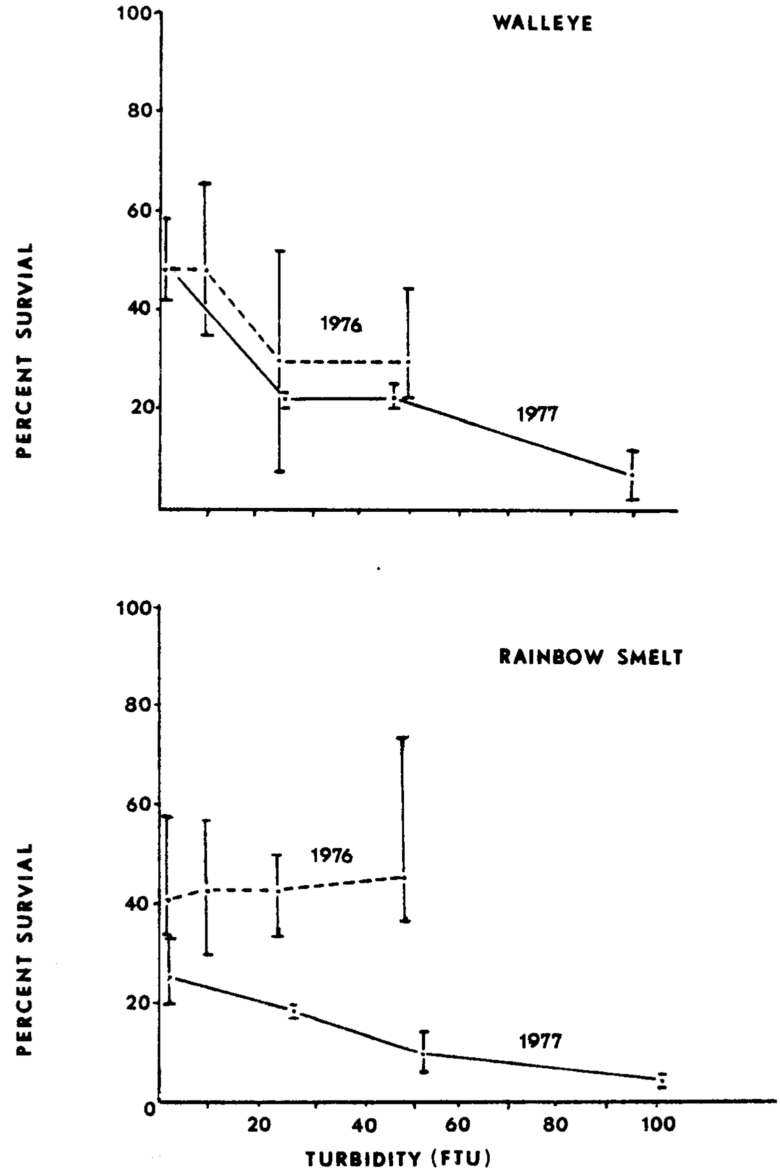

Figure 16. Survival of walleye and rainbow smelt eggs (mean and range) incubated at various turbidities (FTU).

Survival of longnose sucker eggs was not significantly different from the controls (P > 0.1) at any turbidity level (Table 22). Some survival occurred at all treatments but the survival was lower than expected in the controls due to high incidence of fungal growths on the eggs. Two replicates had unusually high survival because of lack of fungal growths in the incubation chambers, and were not included in the analysis (a nominal 50 FTU treatment had 76% survival and a nominal 100 FTU treatment had 70% survival).

Rainbow smelt, walleye, and longnose suckers which spawn in streams broadcast eggs over a rocky substrate, generally in a riffle area. Spawning in riffle areas insures minimal siltation over the substrate. All three species have eggs which are adhesive and attach to the substrate immediately after fertilization (20). The rainbow smelt egg is stalked and waves in the current a short distance off the substrate (<1mm). Longnose suckers and walleye eggs attach directly to the substrate. These adaptations enhance the survival of eggs incubated under conditions of high turbidity as occur in the Nemadji River during April and May.

The results of the tests are difficult to interpret due to the influence of fungal growths on walleye and longnose sucker eggs during the 1978 tests. However, it appears that rainbow smelt and walleye eggs are adversely affected at turbidity levels near 100 FTU at current velocities and sedimentation rates occurring in this study.

A comparison with a similar study on the effects of suspended sediments (69) indicate rainbow smelt and walleye eggs to be more sensitive to suspended sediments than eggs of six species of anadromous and estuarine fish indigenous to Chesapeake Bay. The species tested in the comparison study were: yellow perch (*Perca flavescens*), blueback herring (*Alosa aestivalis*), alewife (*Alosa pseudoharengus*), American shad (*Alosa sapidissima*), white perch (*Morone americana*), and striped bass (*Morone saxatilis*). Eggs of all these species incubate on a substrate much the same as rainbow smelt, walleye and longnose sucker eggs. Only the white perch and striped bass eggs had reduced hatching success due to suspended sediments. The lowest level showing an effect however, was 1000 mg/l (1633 FTU).

The factor which reduces survival as suspended sediments increase is probably reduced dissolved oxygen concentration at the surface of the egg chorion. Such measurements were not made in this study. Lower oxygen levels are assumed as water circulation to the chorion was reduced with increased thickness of sediments on the eggs at increasing turbidities (0 mm, 0 FTU; <1 mm, 25 FTU; 3 mm, 50 FTU; and 6 mm, 100 FTU). Walleye eggs incubated on three substrates in a lake showed reduced survivals with increased biological oxygen demand and conditions less conducive to water agitation (70). Egg survival was poorest on the soft muck-detritus bottom (2.4%), intermediate on a clean, firm sand bottom (8.6%), and best on a clean gravel-rubble bottom (25.0%).

Rainbow smelt and sucker fry (longnose and white sucker fry were not distinguished) were abundant in the Nemadji River (see results of larval drift), demonstrating the ability to survive incubation under prevailing turbidities (up to 250 FTU). Walleye apparently never spawned in the Nemadji River but did spawn in an adjacent watershed with turbidities as high or higher than in the Nemadji River (although hatching success is not known). Prevailing turbidities in the Nemadji River therefore do not prevent either selection of the substrate or hatching success for suckers or rainbow smelt. Results of this study indicate that walleye could also spawn successfully in the river.

The 100 FTU threshold identified as reducing egg survival is probably very low compared to the turbidity required to have similar effects in the natural system. The two factors which contributed most directly to egg mortality throughout this study were sedimentation and fungal growth. It is not suspected that fungal growth would have as significant an effect at naturally occurring egg densities. Turbidities of 100 FTU or higher occur only at high stream discharges in the Nemadji River, resulting in water velocities which do not allow significant sedimentation on the rocky riffle areas utilized for spawning. At present erosional levels in the watershed, it does not seem probable that clay turbidity and sedimentation significantly impacts spawning success of those species which broadcast their eggs except where associated sand sedimentation eliminates important gravel spawning areas. Rates of clay erosion which resulted in some inundation of the spawning areas would be required to affect survival. Only in those tributaries used by spawning salmonids is it likely that relatively low levels of clay erosion and sedimentation have adverse effects on fish production.

Gradient Selection: Brook trout exhibited no preference for either clear or turbid water (chi-square, $P = 0.18$). Turbidities varied from 7.1 FTU in the upstream section to 61.1 FTU in the downstream section of the gradient chamber (Table 23). During the control tests the turbidity averaged 2.4 FTU in both sections.

Two-tailed t-tests showed a significant decrease in the use of cover ($P < 0.001$) and the time associated with the substrate ($P < 0.01$) in the clear upstream sections (7.1 FTU) when compared to the controls (2.4 FTU). Cover was used 45.3% of the time during the turbidity tests and 77.2% during the control tests. Time associated with the substrate was 76.7% during the turbidity tests and 90.6% during the control tests (Table 24).

The data suggests that brook trout do not avoid relatively low levels of turbidity. Brook trout were found in the lower section of Little Balsam Creek which had turbidities up to 63 FTU (43 mg/l). Platts (71) reported brook trout in the South Fork Salmon River which had a mean suspended solids concentration of 54 ppm. Herbert et al.(18) found that the length and weight of brown trout from a portion of the Camel River containing 60 ppm suspended solids differed very little from those in clearwater Cornish streams.

Table 23. Number of brook trout observed in each section in gradient and control tests with mean and standard deviation of turbidities in each section.

Date	Gradient Sec. I No. fish obs.	Gradient Sec. I Turb. (FTU)	Gradient Sec. II No. fish obs.	Gradient Sec. II Turb. (FTU)
11/17-18/77	13	11.9 ± 2.3	43	59.7 ± 11.5
12/5-6/77	25	4.5 ± 0.9	31	56.8 ± 8.1
6/11-12/78	21	8.2 ± 1.2	35	77.0 ± 21.7
6/23-24/78	27	5.1 ± 1.6	29	50.8 ± 14.2
Mean	21.5	7.1	34.5	61.1
Control				
11/28-29/78	15	1	41	1
6/8-9/78	25	2	31	2
6/15-16/78	28	3	28	3
6/28-29/78	28	3.25	28	3.5
Mean	24	2.3	32	2.4

Table 24. Percent use of cover and association with bottom by brook trout in turbidity gradients and clear water controls. Only the upstream section of the gradient test is included due to difficulty in observation of fish in the more turbid downstream section.

Date	Turb. (FTU)	% using cover	% associated with bottom
	Gradient		
11/17-18/77	11.9	69.2	92.3
12/5-6/77	4.5	44.0	72.0
6/11-12/78	8.2	47.6	81.0
6/23-24/78	5.1	33.3	70.3
Mean	7.1	48.5	78.9
	Control		
11/28-29-77	1.0	94.6	100.0
6/8-9/78	2.0	69.6	83.9
6/15-16/78	3.0	51.8	78.6
6/28-29/78	3.4	92.9	100.0
Mean	2.4	77.2	90.6

Brook trout should be expected to be adapted to living in waters which are periodically turbid because discharge and related turbidity normally vary in lotic environments (30). Periodic turbidity may, in fact, be associated with increased food availability as stream invertebrate drift increases and terrestrial foods are washed into the stream during high discharge periods. Surges of turbidity could conceivably result in increased activity and feeding and decreased use of cover. Decreased use of fixed cover could also result from decreased light penetration. MacCrimmon and Kwain (72) found that rainbow trout exhibited a photonegative response to increases in overhead light by retreating under cover. Decreased use of cover in the clear section in the gradient experiments was probably a result of decreased motivation to seek shelter as cover was available in adjacent water in the form of turbidity.

Although reduced light penetration serves as a form of cover, it does not offer many of the stimuli generally associated with fixed cover. Migrations of salmonids occur primarily at night in clear water but may occur throughout the day in highly turbid waters (73, 74). The increases in turbidity may therefore decrease the need for some other forms of cover, but it does not provide a current shelter or thigmotactic or visual reference which have been cited as important in cover selection for brown trout (75).

The decrease in time associated with the substrate with increasing levels of turbidity (Table 24) is probably related to the decreased use of fixed cover and the general decrease in the importance of substrate associated stimuli. The reduced light intensity therefore allowed for less restricted positioning in the water column at the low water velocities used in this study. At higher velocities the substrate may maintain more importance as it provides a current shelter.

Creek chubs preferred the turbid section of the gradient tank ($P < 0.001$) (Table 25). Turbidities average 5.75 FTU in the upstream section and 56.6 FTU in the turbid downstream section. Turbidities averaged 2.25 FTU in both sections during the control tests.

Although the data suggests that creek chubs prefer turbid over clear water, Scott and Crossman (29) state that creek chubs prefer clear water habitats. Trautman (76) lists creek chubs as abundant inhabitants of small streams and creeks which have scoured bottoms of sand, gravel, and boulders, well defined riffles, and pools with brush, roots, or other sufficient cover for retreat. Our field studies found that creek chubs were the most abundant species in turbid sites. They comprised over 50% of the biomass in Elim (site 12) and Skunk Creeks (site 13). Creek chubs were rare or absent in the clear water sites, although other differences such as water temperature or pool depth could affect this distribution. McCrimmon (61) found creek chubs to be much more common in warm streams than in cold.

Copes (77) observed schooling behavior in all types of stream habitat in creek chubs smaller than 180 mm. The levels of turbidity in this study did not affect the schooling behavior of the fish. Schools of creek chubs were seen swimming out of the turbid areas several times. Turbidity may give added protection by visually isolating these smaller forage fish from potential predators. The added cover provided by these relatively low levels of turbidity may enhance the suitability of the habitat for creek chubs.

Table 25. Number of creek chub observed in each section in gradient and control tests with mean and standard deviation of turbidities in each section.

	Gradient			
	Section 1		Section 2	
Date	Adjusted # fish obs.	Turb. (FTU)	Adjusted # fish obs.	Turb. (FTU)
12/7-8/77	44	7.17 ± 1.9	216	54.5 ± 10.6
1/10-11/78	71	6.60 ± 2.3	229	49.0 ± 10.1
7/24-25/78	105	4.82 ± 1.73	175	68.8 ± 17.0
8/3-4/78	145	4.41 ± 1.09	134	54.2 ± 13.7
Mean	91.25	5.75	188.5	56.6
	Control			
12/11-12/78	112	2	168	2
1/4-5/78	230	2	70	2
7/19-20/78	167	2	113	2
8/9-10/78	130	3	135	3
Mean	159.75	2.25	121.5	2.25

The preference of creek chubs and apparent indifference of brook trout to the levels of turbidity used in this study suggest very little negative impact of turbidity on these species. Although trout were not generally found in the turbid tributaries, temperature and discharge were not suitable for salmonid habitat. Creek chubs spawned successfully in the turbid tributaries as young-of-year were quite abundant. However, constant levels of turbidity similar to those in this study would result in levels of sedimentation which would decrease or eliminate spawning success of trout. The direct effects of low level turbidity (not including sedimentation) would therefore seem to have very little effect on distribution of brook trout. The only effect on brook trout seemed to be behavioral changes in cover use and selection. The trout did not avoid turbidity, indicating that low level turbidity in itself would not cause distributional changes within a watershed.

CONCLUSION

The potentially severe effects of erosion and sedimentation on aquatic life should not be underestimated. Adequate documentation exists to identify the severe short and long term effects of soil mismanagement on all levels of the aquatic flora and fauna (reviews 15, 59, 78). It should not be assumed, however, that relatively low levels of erosion are detrimental to all aquatic systems. Analysis of turbid areas of Lake Superior (4) and the Nemadji River System, which is turbid throughout the year due to erosion of unconsolidated glacial lake deposits, indicate that the direct physical effects of low level turbidity and sedimentation are minimal. More important effects within these systems are behavioral changes, many of which could be considered beneficial to indigenous species (4).

Problems attributed to red clay turbidity have included replacement of desirable by less desirable fish species, discouragement of spawning runs, decreased oxygen levels, increased nutrient levels, and general statements of "adverse effects on biological life processes." None of these statements have proven true through our studies in the Nemadji River System. Accusations such as "turbid streams are unattractive and difficult to fish" (79) are harder to refute, and may stand as some of the more damning evidence against moderate turbidities in cool and warm water streams.

The only conclusive detrimental biological effects of relatively low levels of clay sedimentation are the adverse impacts on salmonid reproduction. These have not been addressed through our studies, but adequate documentation exists in the literature to identify the sensitivity of salmonid eggs in redds, which require a flow of water through the gravel, to sedimentation (12, 13, 14). There is also evidence that salmonids will avoid turbid waters, both in lakes (4) and in streams. This seems to be a result of their reliance on sight feeding on drifting macroinvertebrates, at least in lotic systems. Our laboratory studies and available field studies (4, 18, 61), however, indicate that normal turbidities in the Nemadji River System do not exceed the threshold level which would completely discourage use by salmonids. Reproductive success in the Nemadji River System, much of which is too warm for salmonids, does not seem to be greatly affected by existing turbidities judging from both documented reproductive success of smelt and suckers and egg survival bioassays on these species and walleye.

An initial objective of this project was to assess the effects of experimental erosion control procedures on the aquatic biota. Much of this construction was not completed until late in the project period, negating the possibility of a direct assessment of its effects. The difficulties in identifying any changes within the river system due to clay turbidity and sedimentation, however, indicates that factors such as temperature, discharge, and channel form have much greater effects than present levels of clay erosion in the basin. A threshold clay turbidity which directly affects aquatic life or which results in rates of clay sedimentation which might impair reproductive success of species now spawning successfully or respiratory functions of the invertebrates seems to be on the order of 1000 FTU, and this at low to normal flow rates. It is therefore unlikely that the erosion control devices will have any major effect on the biota in areas where clay is the primary erosional product. Rates of erosion must reach that at which the rocky substrate becomes inundated, as in extensive areas of the lower Nemadji River where sand is a major component of the substrate, before significant changes in the fauna will occur. The sand in the lower Nemadji River resulted in an unstable monotypic substrate and a channel form which is uniformly shallow and devoid of cover. The very low macroinvertebrate populations and fish densities in this area were the only severe effects of erosion identified in the river system. If sand erosion in the lower areas of the Nemadji River could be curbed, the 25 km of river which is now dominated by this sandy substrate may revert to a much more productive pool-riffle configuration.

Existing levels of streambank erosion in this river system should therefore not be assumed to have widespread detrimental effects on the aquatic biota. The watershed is relatively unperturbed at this time and erosion control practices cannot be expected to have a significant positive effect on aquatic resources. Careful management along roadside right-of-ways and curbing extensive cattle grazing of streambanks will help to prevent widespread degradation of the system, but the most positive results of the present erosion control engineering studies will probably be the development of techniques to prevent slippage of hillsides and losses of roads and personal property.

SUMMARY

1. Red clay does not contribute significant quantities of nutrients to Lake Superior but may serve to transport nutrients contributed from point sources.

2. Oxygen levels are not significantly affected by red clay or associated organics.

3. Primary production does not appear to be significantly affected by existing turbidities within the range of depths at which most production occurs in these relatively shallow streams.

4. Bacteria exhibit no definite trends with turbidity within sites, but do seem to have higher counts in turbid

than in non-turbid sites. Fungal counts exhibit opposite trends. Bacterial and fungal populations are generally beneficial to the aquatic system as they are the primary food source for many of the macroinvertebrates.

5. Number of macroinvertebrates per unit area, total number of taxa, diversity, and biomass are not significantly affected by clay turbidity and siltation within the Nemadji River System.

6. Substrate size had much greater effects on macroinvertebrates than turbidity and sedimentation. Only where sand was the primary product were significant detrimental effects of erosion identified.

7. All genera of insects which occurred in clear streams also occurred in turbid streams. Certain silt-loving insects, especially certain mayflies and beetle larvae, were found only in the turbid streams.

8. Laboratory monitoring of activity and respiration of the stonefly *Pteronarcys dorsata* demonstrated no significant effects at turbidity levels normally encountered in the Nemadji River System.

9. Fish populations were not demonstrated to change as a result of turbid conditions. Water temperature and discharge differences between turbid and clear water sites accounted for species changes. All species complexes benefitted by increased cover which is harder to maintain in turbid streams due to increased tendencies for slippage at toes of the clay banks.

10. Walleye in the lower Nemadji River, the Duluth-Superior Harbor, and Lake Superior benefit from red clay turbidity as it enables them to inhabit the shallow, more productive waters. Availability of prey fish populations in the Nemadji River appears to be a factor limiting residency of walleye and other predators.

11. Rainbow smelt and four species of suckers successfully reproduce in the turbid areas of the Nemadji River System.

12. Egg survival bioassays with walleye and rainbow smelt indicated decreased survival at turbidities over 10 FTU. Survival was at least half of control at turbidities prevalent in the Nemadji River. Levels of sedimentation in the bioassay were much higher than in the natural system, probably resulting in higher egg mortality than would normally occur.

13. Channel form and available cover are the primary factors affecting fish population size for all species com-

plexes in the Nemadji River System.

RECOMMENDATIONS

The major effect of the red clays on the aquatic biota are associated with characteristics of the soils which affect channel form. Undercut banks and other channel characteristics which provide cover have major impacts on all types of fish populations. The major recommendations which can be identified through this study are therefore related to preservation of the toes of slopes to maintain undercut banks (though they seldom occur in these soils), steep sided channels, and pool depth, all of which provide forms of cover. Recommendations are as follows:

1. Retaining peak discharges after rainfall could slow erosion rates and preserve streambanks. Floodwater retaining structures may be effective, but barriers in streams and substitution of a lake for a stream environment is potentially disruptive and self-defeating. More desirable controls would be retention by adequate vegetative cover and leaf litter and land use practices which minimize runoff.

2. Vegetation which stabilizes streambanks may allow undercutting, steeper banks, and deeper pools. Woody root systems provide excellent cover for forage fish and harbored major fish concentrations in study streams.

3. Removal of stumps and other snags is definitely detrimental to fish populations. The pools eroded around such structures coupled with the associated cover provide some of the best habitat in these turbid streams. The erosion is insignificant compared to benefits to fish populations.

4. The grazing of cattle and other livestock on streambanks breaks down slopes, eliminates cover, potentially decreases stream depth, and generally disrupts the stream biota. Livestock exclusion is recommended.

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APPENDICES

Appendix A -

Summary of Physical and Chemical Characteristics

of Sampling Sites, 1975-1977.

SITE 1 - NEMADJI RIVER

Bank Erosion - None

Streambank Vegetation - 30% grass, 70% brush

Normal Water Color - Brown

Average Width - 46 m

Average Depth - 2.5 m

Date	8/19 1975	8/29 1975	9/29 1975	10/20 1975	12/8 1975	4/16 1976	4/29 1976	5/5 1976
Thalweg Velocity (mps)	<0.015 <0.05	<0.015 <0.05	0.04	---	---	---	---	---
Turbidity (ftu)	---	16	31.5	12	28.5	101	95	---
Dissolved Oxygen (ppm)	6.0	7.9	8.9	8.8	11.7	9.3	6.0	9.7
Temperature (^{o}C)	21.0	18.9	11.3	11.8	1.2	10.5	11.2	10.8
Conductivity (μmho)	295	260	138	142	82	85	123	122
% Oxygen Saturation	67.8	85.6	81.4	81.5	82.6	83.0	54.6	87.7
pH	---	---	---	---	7.43	6.95	---	7.5

<u>Substrate</u> - clay, silt, sand

(continued)

Site 1 (continued)

Date	5/17 1976	6/4 1976	6/14 1976	8/24 1976	9/13 1976	10/11 1976	4/21 1977	<u>Range</u>	<u>Avg</u>
Thalweg Velocity (mps)	---	---	---	---	---	---	---	---	---
Turbidity (ftu)	12	---	24	25	21.5	33.5	220	12-220	51.6
Dissolved Oxygen (ppm)	9.3	---	---	---	8.3	8.2	---	6-11.7	8.6
Temperature (^{o}C)	16.8	17.2	22.2	---	18.8	9.4	---	1.2-22.2	13.9
Conductivity (μmho)	198	---	300	---	278	214	---	82-300	186.4
% Oxygen Saturation	96.4	---	---	---	89.7	71.7	---	54.6-96.4	80.2
pH	---	---	6.8	---	7.28	---	---	6.8-7.5	7.2

SITE 2 - NEMADJI RIVER

Bank Erosion - Moderate to Severe

Streambank Vegetation - 18% grass, 50% brush, 10% deciduous, 30% barren

Normal Water Color - Brown

Average Width - 22 m

Average Depth - 2.5 m

Date	8/19 1975	8/29 1975	9/29 1975	10/20 1975	12/8 1975
Thalweg Velocity (mps)	---	<0.015	<0.015	0.12	---
Turbidity (ftu)	7	13	14	12.5	29
Dissolved Oxygen (ppm)	6.7	8.6	9.1	10.6	11.9
Temperature (^{o}C)	19.5	17.8	12.0	7.5	1.5
Conductivity (μmho)	263	238	141	169	80
% Oxygen Saturation	73.5	91.1	84.7	88.4	84.7
pH	---	---	---	---	7.35

Substrate - mostly sand, some clay, fine gravel, rubble

SITE 3 - NEMADJI RIVER

Bank Erosion - Slight

Streambank Vegetation - 35% grasses, 55% brush, 10% barren

Normal Water Color - Brown

Average Width - 11.3 m

Average Depth - 0.4 m

Date	9/4 1975	9/17 1975	10/1 1975	10/20 1975	11/17 1975	12/8 1975
Thalweg Velocity (mps)	0.38	---	0.38	0.44	0.59	---
Turbidity (ftu)	10	10	6	12.5	54	222.5 (slush)
Dissolved Oxygen (ppm)	9.9	---	10.4	10.9	13.3	12.1
Temperature (^{o}C)	20.1	14.9	9.6	7.7	1.3	1.2
Conductivity (µmho)	251	220	170	182	95	172
% Oxygen Saturation	110	---	91.4	91.4	94.1	85.4
pH	---	---	---	---	---	7.8

Substrate - 10% fine gravel
90% sand

SITE 4 - NEMADJI RIVER

Bank Erosion - Slight to Moderate

Streambank Vegetation - 25% grass, 70% brush, 5% barren

Normal Water Color - Brown

Average Width - 12.8 m

Average Depth - 0.3 m

Date	9/4 1975	9/17 1975	10/2 1975	10/22 1975	11/17 1975	12/5 1975	4/16 1976	4/30 1976
Thalweg Velocity (mps)	0.45	---	0.29	0.31 1.38	0.56 1.83	---	---	---
Turbidity (ftu)	10	10	7	10	73.5	27	92.5	95
Dissolved Oxygen (ppm)	10.1	---	10.6	11.5	13.4	12.0	9.2	6.0
Temperature (^{o}C)	19.9	13.3	11.3	7.6	1.9	1.3	10.3	11.2
Conductivity (μmho)	242	223	185	183	110	210	99	123
% Oxygen Saturation	112	---	97	96.2	96.4	84.9	82.1	54.6
pH	---	---	---	---	---	7.35	6.75	---

Substrate - 12% fine gravel
88% sand

(continued)

Site 4 (continued)

Date	5/17 1976	6/2 1976	6/14 1976	6/29 1976	8/9 1976	8/24 1976	9/13 1976	10/11 1976
Thalweg Velocity (mps)	---	---	---	---	---	---	---	---
Turbidity (ftu)	21	20.5	42	---	18	---	16.5	20
Dissolved Oxygen (ppm)	9.7	9.4	---	---	9.4	---	8.7	11.3
Temperature (^{o}C)	15.1	21.2	21.3	19.8	20.2	25.0	17.8	8.3
Conductivity (µmho)	205	---	263	200	261	280	258	205
% Oxygen Saturation	96.9	106.7	---	---	104.7	---	92.2	96.2
pH	---	---	7.2	---	7.09	---	7.4	---

continued

Site 4 (continued)

Date	4/21 1977	5/9 1977	6/9 1977	8/17 1977	9/14 1977	10/26 1977	Range	Avg
Thalweg Velocity (mps)	---	---	---	---	---	---	---	---
Turbidity (ftu)	300	32	14	28	40	29.5	7-300	45.3
Dissolved Oxygen (ppm)	11.95	7.4	9.4	---	9.2	11.8	6.0-13.4	10.06
Temperature (^{O}C)	5.9	10.5	14.4	18.7	14.6	8	1.3-25.0	13.5
Conductivity (mho)	128	182	170	---	120	100	99-280	187.4
% Oxygen Saturation	95.7	66.4	92.4	---	90.9	99.7	54.6-112	92.1
pH	---	---	---	---	---	---	6.8-7.4	7.2

SITE 5 - NEMADJI RIVER

Bank Erosion - Slight

Streambank Vegetation - 30% grass, 60% brush, 5% deciduous, 5% barren

Normal Water Color - Brown

Average Width - 20.7 m

Average Depth .5 m

Date	9/11 1975	10/1 1975	10/22 1975	11/17 1975	12/10 1975	4/16 1976	4/30 1976
Pool Velocity (mps)	0.26	0.30	0.33	0.56	---	---	---
Riffle Velocity (mps)	0.84	0.90	1.00	---	---	---	---
Turbidity (ftu)	9	4	9	73.5	82	89.5	87
Dissolved Oxygen (ppm)	11.7	10.4	11.4	13.4	12.2	9.8	7.0
Temperature (°C)	16.0	9.5	8.2	1.9	1.6	10.3	10.9
Conductivity (μmho)	204	158	167	110	98	110	123
% Oxygen Saturation	119.1	91.1	96.8	96.4	87.0	87.5	64.2
pH	---	---	---	---	7.7	6.62	---

Substrate - 5% rubble, 20% coarse gravel, 15% medium gravel, 15% fine gravel, 45% sand

(continued)

Site 5 (continued)

Date	5/17 1976	6/4 1976	6/14 1976	6/29 1976	8/9 1976	9/13 1976	10/11 1976
Pool Velocity (mps)	---	---	---	---	---	---	---
Riffle Velocity (mps)	---	---	---	---	---	---	---
Turbidity (ftu)	15	10.5	30	---	21	15.5	14
Dissolved Oxygen (ppm)	10.1	---	---	---	9.9	9.45	11.2
Temperature (^{o}C)	17.5	13.9	23.3	22.7	21.1	18.2	7.1
Conductivity (μmho)	225	---	309	210	268	247	186
% Oxygen Saturation	106.3	---	---	---	112.2	100.9	92.5
pH	---	---	---	---	7.15	7.4	---

(continued)

Site 5 (continued)

Date	4/21 1977	5/9 1977	6/9 1977	8/17 1977	9/14 1977	10/26 1977	Range	Avg
Pool Velocity (mps)	---	---	---	---	---	---	---	---
Riffle Velocity (mps)	---	---	---	---	---	---	---	---
Turbidity (ftu)	400	22	12	21	41	24	4-460	51.5
Dissolved Oxygen (ppm)	---	9.2	10	---	9.6	12.4	7.0-13.4	10.5
Temperature (°C)	6.5	14.8	15	18.5	14	7.5	1.6-23.3	12.9
Conductivity (μmho)	111	192	183	---	140	70	70-309	172.8
% Oxygen Saturation	---	91.3	99.7	---	93.6	103.4	64.2-119.1	96.1
pH	---	---	---	---	---	---	6.62-7.7	7.2

SITE 6 - NEMADJI RIVER

Bank Erosion - Slight

Streambank Vegetation - 20% grass, 40% brush, 5% herbaceous, 10% coniferous, 20% deciduous, 5% barren

Normal Water Color - Brown

Average Width - 10.7 m

Average Depth - 0.5 m

Date	9/11 1975	10/3 1975	10/24 1975	11/19 1975	12/10 1975
Pool Velocity (mps)	---	<0.015 <0.05	0.03 0.1	---	---
Riffle Velocity (mps)	---	0.69 2.28	0.79 2.58	---	---
Turbidity (ftu)	12	8	8.5	62.5	16
Dissolved Oxygen (ppm)	10.6	10.0	10.4	---	12.4
Temperature (^{o}C)	15.4	8.5	7.8	---	1.2
Conductivity (μmho)	136	102	114	---	72
% Oxygen Saturation	106.5	85.5	87.4	---	87.5
pH	---	---	---	---	7.3

<u>Substrate</u> - 15% boulder
30% rubble
20% coarse gravel
10% medium gravel
5% fine gravel
20% sand

SITE 7 - BALSAM CREEK

Bank Erosion - Moderate

Streambank Vegetation - 10% grass, 60% brush, 5% herbaceous, 5% coniferous, 10% deciduous, 10% barren

Normal Water Color - Brown

Average Width - 8.0 m

Average Depth - 0.6 m

Date	9/4 1975	9/17 1975	10/2 1975	10/22 1975	11/17 1975	12/5 1975
Pool Velocity (mps)	0.13	---	0.13 0.43	0.08 0.27	0.55 1.80	---
Riffle Velocity (mps)	---	---	0.53 1.75	0.78 2.55	1.65 5.40	---
Turbidity (ftu)	32	---	22	19	67.5	20
Dissolved Oxygen (ppm)	9.5	---	10.0	10.9	13.4	12.4
Temperature (^{o}C)	16.7	11.0	8.3	7.8	1.7	1.2
Conductivity (μmho)	171	169	127	138	75	245
% Oxygen Saturation	98.2	---	85.1	91.6	95.9	87.5
pH	---	---	---	---	---	7.6

<u>Substrate</u> - 60% rubble
5% coarse gravel
20% sand
10% silt
5% clay

SITE 8 - LITTLE BALSAM CREEK

Bank Erosion - Moderate

Streambank Vegetation - 20% grass, 35% brush, 15% gerbaceous, 25% deciduous, 5% barren

Normal Water Color - Clear

Average Width - 3.7 m

Average Depth - 0.75 m

Date	8/19 1975	8/27 1975	9/30 1975	10/21 1975	11/18 1975	12/5 1975	4/16 1976	4/27 1976
Pool Velocity (mps)	---	---	0.11	0.09	0.47	---	---	---
Riffle Velocity (mps)	---	---	0.81	0.65	1.49	---	---	---
Turbidity (ftu)	---	2	2	2.5	63	6	10	3.5
Dissolved Oxygen (ppm)	9.3	10.2	10.5	11.2	12.2	12.6	10.9	9.8
Temperature (°C)	18.2	15	10.6	9.3	3.1	1.8	10.3	11.3
Conductivity (μmho)	165	179	148	144	79	116	48	70
% Oxygen Saturation	99.4	101.7	94.5	97.6	90.6	90.4	97.3	89.0
pH	---	---	---	---	---	7.7	6.65	---

Substrate - 25% rubble, 15% coarse gravel, 5% medium gravel, 10% fine gravel, 35% sand, 10% silt

(continued)

Site 8 (continued)

Date	5/18 1976	6/2 1976	6/14 1976	8/9 1976	9/13 1976	10/11 1976	3/3 1977	4/21 1977	5/12 1977
Pool Velocity (mps)	---	---	---	---	---	---	---	---	---
Riffle Velocity (mps)	---	---	---	---	---	---	---	---	---
Turbidity (ftu)	3	2	12	2	3	5	22	36	3
Dissolved Oxygen (ppm)	11.4	12.8	---	10.8	10.05	11.6	---	---	11
Temperature (°C)	13.9	13.4	16.0	14.8	15.0	7.9	0.75	5.4	7.5
Conductivity (μmho)	148	---	178	175	182	149	52	72	125
% Oxygen Saturation	110.9	123.1	---	107.1	100.2	97.7	---	---	94.0
pH	7.6	---	7.1	---	7.5	---	---	---	---

(continued)

Site 8 (continued)

Date	6/22 1977	8/17 1977	9/14 1977	10/26 1977	Range	Avg
Pool Velocity (mps)	---	---	---	---	---	---
Riffle Velocity (mps)	---	---	---	---	---	---
Turbidity (ftu)	3	2	3	24	2-63	10.5
Dissolved Oxygen (ppm)	11	---	9.2	12.1	9.2-12.8	11.0
Temperature (°C)	12.5	11.5	13.3	6.2	1.8-18.2	10.4
Conductivity (µmho)	140	---	111	57	48-182	123.1
% Oxygen Saturation	103.6	---	88.2	97.6	88.2-123.1	99.0
pH	---	---	---	---	6.7-7.7	7.3

SITE 9 - LITTLE BALSAM CREEK

Bank Erosion - Slight

Streambank Vegetation - 25% grass, 30% brush, 30% herbaceous, 5% deciduous, 5% coniferous, 5% barren

Average Width - 2.0 m

Average Depth - 0.15 m

Date	8/19 1975	8/27 1975	9/30 1975	10/21 1975	11/18 1975	12/5 1975	4/16 1976	4/27 1976	5/18 1976
Pool Velocity (mps)	---	---	0.04	0.02	0.15	---	---	---	---
Riffle Velocity (mps)	---	---	0.32	0.44	0.81	---	---	---	---
Turbidity (ftu)	---	3	5	3	5.5	6.5	4	4	5
Dissolved Oxygen (ppm)	7.4	9.2	8.3	8.85	12.2	12.1	9.7	9.9	10.0
Temperature (^{o}C)	12.7	12.7	10.2	9.0	3.2	1.5	10.2	9.2	16.1
Conductivity (μmho)	150	139	100	91	47	39	30	33	95
% Oxygen Saturation	70.0	87.0	74.0	76.6	90.9	86.1	86.6	86.0	102.1
pH	---	---	---	---	---	7.45	6.65	---	6.55

<u>Substrate</u> - 20% rubble
10% coarse gravel
5% medium gravel
5% fine gravel
55% sand
5% silt

(continued)

Site 9 (continued)

Date	6/2 1976	6/14 1976	6/29 1976	8/9 1976	9/13 1976	10/11 1976	4/21 1977	5/12 1977
Pool Velocity (mps)	---	---	---	---	---	---	---	---
Riffle Velocity (mps)	---	---	---	---	---	---	---	---
Turbidity (ftu)	5.5	8.5	5	3	3.5	5	4.5	2
Dissolved Oxygen (ppm)	11.3	---	---	9.2	7.8	6.7	---	9.5
Temperature (°C)	13.0	15.1	14.7	12.5	12.4	8.6	5.1	11.2
Conductivity (µmho)	---	130	122	170	179	165	48	92
% Oxygen Saturation	107.6	---	---	86.6	73.2	57.4	---	86.8
pH	---	6.9	---	---	7.38	---	---	---

(continued)

Site 9 (continued)

Date	6/22 1977	8/17 1977	9/14 1977	10/26 1977	Range	Avg
Pool Velocity (mps)	---	---	---	---	---	---
Riffle Velocity (mps)	---	---	---	---	---	---
Turbidity (ftu)	3	4	5.5	7	2-8.5	4.6
Dissolved Oxygen (ppm)	8.2	---	8.4	11.6	6.7-12.2	9.4
Temperature (°C)	15.0	10.5	12.5	7.0	1.5-16.1	10.6
Conductivity (μmho)	102	---	65	35	30-179	96.4
% Oxygen Saturation	81.8	---	79.1	95.6	57.4-107.6	84.0
pH	---	---	---	---	6.6-7.5	7.0

SITE 10 - EMPIRE CREEK

Bank Erosion - Slight

Streambank Vegetation - 20% grass, 5% brush, 30% herbaceous, 5% coniferous, 40% deciduous

Normal Water Color - Clear

Average Width - 2.0 m

Average Depth - 0.25 m

Date	8/27 1975	9/29 1975	10/23 1975	11/18 1975	12/5 1975	4/16 1976	4/27 1976	5/21 1976	6/2 1976
Pool Velocity (mps)	---	0.09	0.14	0.31	---	---	---	---	---
Riffle Velocity (mps)	---	0.83	0.66	0.56	---	---	---	---	---
Turbidity (ftu)	2	2	3.5	28	11	5.5	5	2	2
Dissolved Oxygen (ppm)	10.4	9.8	10.4	11.4	12.8	10.0	9.8	11.2	10.6
Temperature (^{o}C)	12.1	10.5	7	4.1	1.5	9.0	9.1	10	15
Conductivity (μmho)	135	133	122	70	60	47	66	120	---
% Oxygen Saturation	97.0	88.0	85.7	87.0	91.1	86.2	86.2	99.4	105.7
pH	---	---	---	---	8.0	6.85	---	7.5	---

<u>Substrate</u> - 5% coarse gravel
10% medium gravel
15% fine gravel
70% sand

(continued)

Site 10 (continued)

Date	6/29 1976	8/9 1976	9/13 1976	10/11 1976	4/21 1977	5/12 1977	6/22 1977	8/17 1977	9/14 1977	10/26 1977	Range	Avg
Pool Velocity (mps)	---	---	---	---	---	---	---	---	---	---	---	---
Riffle Velocity (mps)	---	---	---	---	---	---	---	---	---	---	---	---
Turbidity (ftu)	12	3	3.5	6	24	2	1	2	2	5	1-28	6.4
Dissolved Oxygen (ppm)	---	10.6	9.4	10.6	12.5	10.6	11.2	---	9.6	11.8	9.4-12.8	10.6
Temperagure ($^{\circ}C$)	14.9	14.0	14.9	6.8	4.3	6	11.5	11.0	12.5	6.5	1.5-15	9.5
Conductivity (μmho)	158	182	191	145	70	120	150	---	110	60	47-191	114.1
% Oxygen Saturation	---	103.3	93.6	86.8	95.9	85.1	103.0	---	90.4	95.9	85.1-105.7	93.0
pH	6.8	---	7.42	---	---	---	---	---	---	---	6.8-8.0	7.3

SITE 11 - SKUNK CREEK

Bank Erosion - Moderate to Severe

Streambank Vegetation - 35% grass, 35% brush, 5% coniferous, 10% deciduous, 15% barren

Normal Water Color - Brown

Average Width - 3.0 m

Average Depth - 0.45 m

Date	8/20 1975	9/11 1975	10/3 1975	10/23 1975	11/19 1975	12/10 1975	4/16 1976	4/28 1976	5/17 1976
Pool Velocity (mps)	---	<0.015 <0.05	<0.015 <0.05	<0.015 <0.05	0.41 1.33	---	---	---	---
Riffle Velocity (mps)	---	---	0.34	0.69 2.25	1.45 4.75	---	---	---	---
Turbidity (ftu)	18	12	12	39.5	114.5	28.5	30.5	54	43
Dissolved Oxygen (ppm)	8.8	10.4	10	10.6	12.3	12.4	10.1	11.0	10.9
Temperature (°C)	16.9	12.4	7.6	7.4	3.4	1.7	9.8	8.1	16.9
Conductivity (µmho)	190	165	145	132	98	98	80	90	172
% Oxygen Saturation	91.4	97.7	83.6	88.2	92.1	88.7	88.6	88.6	113
pH	---	---	---	---	---	7.7	6.55	---	7.9

Substrate - 35% rubble, 5% coarse gravel, 10% sand, 40% silt, 10% clay

(continued)

Site 11 (continued)

Date	6/3 1976	6/14 1976	6/30 1976	8/9 1976	9/13 1976	10/11 1976	3/30 1977	4/21 1977	5/12 1977
Pool Velocity (mps)	---	---	---	---	---	---	---	---	---
Riffle Velocity (mps)	---	---	---	---	---	---	---	---	---
Turbidity (ftu)	45	52	46	29	21.5	27	26	200	12
Dissolved Oxygen (ppm)	9.4	---	---	9.9	8.85	10.1	---	---	9.6
Temperature (°C)	21.1	20.9	17.2	19.5	16	5.0	.5	3.1	13
Conductivity (µmho)	---	200	130	198	232	148	43	108	180
% Oxygen Saturation	106.6	---	---	108.6	90.1	80.0	---	---	91.4
pH	---	---	---	6.9	7.3	---	---	---	---

(continued)

Site 11 (continued)

Date	6/22 1977	8/18 1977	9/14 1977	10/26 1977	Range	Avg
Pool Velocity (mps)	---	---	---	---	---	---
Riffle Velocity (mps)	---	---	---	---	---	---
Turbidity (ftu)	12	14	28	29.5	11.5-200	40.6
Dissolved Oxygen (ppm)	9.0	---	9.8	12.4	8.8-12.4	10.3
Temperature (°C)	17	13	14.5	7.0	.5-21.1	11.5
Conductivity (μmho)	155	---	133	89	43-232	139.3
% Oxygen Saturation	93.7	---	96.6	102.1	80-113	94.2
pH	---	---	---	---	6.6-7.9	7.3

SITE 12 - ELIM CREEK

Bank Erosion - Moderate

Streambank Vegetation - 40% grass, 45% brush, 5% coniferous, 5% deciduous, 5% barren

Normal Water Color - Clear to brown

Average Width - Intermittent

Average Depth - Intermittent

Date	9/10 1975	10/3 1975	10/24 1975	11/19 1975	12/10 1975	4/16 1976	4/28 1976	5/17 1976	6/3 1976	6/14 1976	6/30 1976
Pool Velocity (mps)	dry	---	---	0.62	---	---	---	---	---	---	---
Riffle Velocity (mps)	dry	---	---	1.26	---	---	---	---	---	---	---
Turbidity (ftu)	dry	4	140	107.5	18	18.5	18.5	16	25	86	46
Dissolved Oxygen (ppm)	dry	---	---	12.3	12.2	10.3	10.7	10.4	9.4	---	---
Temperature (^{o}C)	dry	---	---	4.8	1.9	10.1	8.9	18.3	16.8	20.0	16.5
Conductivity (μmho)	dry	---	---	111	125	118	140	276	---	221	160
% Oxygen Saturation	---	---	---	95.6	87.8	91.1	92.2	111.4	97.4	---	---
pH	---	---	---	---	7.3	6.7	---	7.8	---	---	---

<u>Substrate</u> - 20% rubble, 40% coarse gravel, 20% medium gravel, 10% sand, 10% clay

(continued)

Site 12 (continued)

Date	8/9 1976	9/13 1976	10/11 1976	4/21 1977	5/12 1977	6/22 1977	8/18 1977	9/14 1977	10/26 1977	Range	Avg
Pool Velocity (mps)	---	---	---	---	---	---	---	---	---	---	---
Riffle Velocity (mps)	---	---	---	---	---	---	---	---	---	---	---
Turbidity (ftu)	5	---	---	500	7	40	16	82	32	4-500	68.3
Dissolved Oxygen (ppm)	11.4	---	---	---	9.2	10.7	---	8.0	12.8	8.0-12.8	10.7
Temperature (°C)	19.3	dry	dry	7.9	14	14.2	13	14.8	7.5	1.9-20.0	12.5
Conductivity (μmho)	228	dry	dry	160	250	220	---	155	110	110-276	174.9
% Oxygen Saturation	124.6	---	---	---	89.7	104.7	---	79.4	106.8	79.4-124.6	98.2
pH	6.9	---	---	---	---	---	---	---	---	6.7-7.8	7.2

SITE 13 - SKUNK CREEK

Bank Erosion - Slight to Severe

Streambank Vegetation - 5% grass, 35% brush, 20% coniferous, 25% deciduous, 15% barren

Norman Water Color - Brown

Average Width - 4.9 m

Average Depth - 1.0 m

Date	8/20 1975	9/10 1975	10/3 1975	10/24 1975	11/19 1975	12/10 1975	4/16 1976	4/28 1976	5/17 1976
Pool Velocity (mps)	---	<0.015 <0.05	<0.015 <0.05	<0.015 0.32	---	---	---	---	---
Riffle Velocity (mps)	---	---	0.22	0.64	---	---	---	---	---
Turbidity (ftu)	22	21	13	135	117	28	36	38	33
Dissolved Oxygen (ppm)	7.8	10.1	10.1	11.0	---	12.2	9.4	10.6	10.2
Temperature (^{o}C)	16.7	13.0	10.3	7.6	---	1.8	10.0	6.8	17.1
Conductivity (μmho)	190	178	170	152	---	150	98	100	182
% Oxygen Saturation	80.1	96.2	90.3	92-0	---	87.5	83.2	86.9	106.1
pH	---	---	---	---	---	7.1	6.65	---	---

<u>Substrate</u> - 30% rubble
5% sand
20% silt
45% clay

(continued)

Site 13 (continued)

Date	6/3 1976	6/14 1976	6/30 1976	8/9 1976	9/13 1976	10/11 1976	3/30 1977	4/21 1977	5/12 1977
Pool Velocity (mps)	---	---	---	---	---	---	---	---	---
Riffle Velocity (mps)	---	---	---	---	---	---	---	---	---
Turbidity (ftu)	41	68	74	32	500	27	89	260	10
Dissolved Oxygen (ppm)	9.7	---	---	10.6	7.0	10.6	---	---	9.9
Temperature (°C)	16	20.8	15.8	21.9	15.8	6.8	0.3	3.9	12
Conductivity (µmho)	---	192	140	215	238	160	59	115	180
% Oxygen Saturation	98.8	---	---	122.1	70.5	86.8	---	---	92.1
pH	---	---	---	7.0	7.2	---	---	---	---

(continued)

Site 13 (continued)

Date	6/22 1977	8/18 1977	9/14 1977	10/26 1977	Range	Avg
Pool Velocity (mps)	---	---	---	---	---	---
Riffle Velocity (mps)	---	---	---	---	---	---
Turbidity (ftu)	13	15	42	24.5	10-500	54.2*
Dissolved Oxygen (ppm)	9.4	---	9.0	12.7	7.0-12.7	10.0
Temperature (^{o}C)	17	12	15	7.5	0.3-21.9	11.8
Conductivity (μmho)	165	---	143	99	59-238	154.0
% Oxygen Saturation	97.8	---	89.7	105.9	70.5-122.1	92.9
pH	---	---	---	---	6.7-7.2	7.0

* not including 9/13/76

APPENDIX B. Turbidity and nitrite, nitrate, orthophosphate, and total phosphate levels in Little Balsam Creek, Empire Creek, Elim Creek above and below the dam, and Skunk Creek below Elim Creek and above and at the Hanson Dam.

LITTLE BALSAM

Date	Turbidity (FTU)	Nitrite µg/l	Nitrate µg/l	Ortho-Phosphate µg/l	Total Phosphorus µg/l
9/7/76	2	0.0*	59.5	0.0*	0.0*
9/27/76	3	0.0*	20.53	0.0*	132.76
10/11/76	5	0.0*	0.0*	0.0*	0.0*
11/2/76	1.2	0.0*	20.65	0.0*	176.31
3/31/77	22	0.0*	73.97	0.0*	612.8
4/18/77	8.1	0.0*	0.0*	868.37	1001.75
5/9/77	3	0.0*	336.2	136.2	541.27
6/6/77	3	0.0*	23.2	---	---
6/20/77	3	0.0*	42.1	---	---
8/1/77	3	0.0*	27.93	133.23	793.43
8/29/77	5	0.0*	18.12	139.62	---
9/12/77	3	---	---	15.32	924.39
10/3/77	3	0.0*	17.72	42.86	614.41
10/24/77	4	0.0*	15.86	0.0*	154.03
12/12/77	3	0.0*	39.91	57.69	1219.17
3/29/78	18	15.90	533.80	50.56	1005.86
4/17/78	25	---	50.39	28.48	---
5/9/78	21	---	---	47.54	---
5/11/78	7	---	---	589.10	---
5/16/78	16	---	---	1393.32	---
5/23/78	4	---	---	463.47	---

*below minimum detectable levels
(continued)

Appendix B (continued)

EMPIRE CREEK

Date	Turbidity (FTU)	Nitrite µg/l	Nitrate µg/l	Ortho-Phosphate µg/l	Total Phosphorus µg/l
9/7/76	2	0.0*	52.8	0.0*	307.2
8/27/76	2	0.0*	0.0*	0.0*	376.20
10/11/76	6	0.0*	0.0*	0.0*	0.0*
11/2/76	2	0.0*	0.0*	0.0*	66.98
4/18/77	6	0.0*	73.12	34.42	382.76
5/9/77	2	0.0*	96.2	179.24	294.43
6/6/77	2	0.0*	24.8	---	---
6/20/77	2	0.0*	39.1	---	---
8/1/77	2	0.0*	11.66	141.79	727.84
8/29/77	4	0.0*	14.42	52.25	---
9/12/77	2	0.0*	10.48	0.0*	12.38
10/3/77	3	0.0*	0.0*	0.0*	0.0*
10/24/77	2	0.0*	0.0*	0.0*	90.96
12/12/77	3	0.0*	19.29	0.0*	328.13
3/29/78	7	14.64	263.54	886.88	1094.54
4/17/78	25	---	27.45	25.48	---
5/9/78	12	---	---	44.61	---
5/11/78	6	---	---	437.44	---
5/16/78	4	---	---	839.45	---
5/23/78	4	---	---	288.56	---

* below minimum detectable levels

(continued)

Appendix B (continued)

ELIM ABOVE DAM

Date	Turbidity (FTU)	Nitrite µg/l	Nitrate µg/l	Ortho-Phosphate µg/l	Total Phosphorus µg/l
8/3/76	15	0.0*	0.0*	0.0*	0.0*
9/7/76	dry	stream	bed		
9/27/76	dry	stream	bed		
10/11/76	dry	stream	bed		
3/31/77	18	11.31	215.9	0.0*	---
4/18/77	33	16.32	338.88	649.52	777.72
5/9/77	3	0.0*	14.2	150.13	721.01
6/6/77	7	0.0*	32.4	---	---
6/20/77	8	26.4	72.3	---	---
8/1/77	78	0.0*	26.17	471.32	490.75
8/29/77	25	0.0*	28.91	81.37	---
9/12/77	8	0.0*	15.65	17.36	890.84
10/3/77	4	0.0*	11.95	0.0	376.93
10/24/77	6	0.0*	16.24	15.38	788.66
12/12/77	26	11.4	40.52	57.24	269.93

*below minimum detectable levels

(continued)

Appendix B (continued)

ELIM CREEK BELOW DAM

Date	Turbidity (FTU)	Nitrite μg/l	Nitrate μg/l	Ortho-Phosphate μg/l	Total Phosphorus μg/l
8/3/76	13	0.0*	0.0*	0.0*	0.0*
9/7/76	dry	stream	bed		
9/27/76	dry	stream	bed		
10/11/76	dry	stream	bed		
3/31/77	350	25.92	161.21	282.99	420.31
4/18/77	21	0.0*	0.0*	793.26	872.25
5/9/77	7	0.0*	0.0*	160.25	712.15
6/6/77	40	0.0*	30.5	---	---
6/20/77	36	0.0*	41.7	---	---
8/1/77	54	0.0*	20.07	365.53	768.77
8/29/77	33	11.64	30.66	202.38	---
9/12/77	82	11.77	27.95	22.03	857.29
10/3/77	38	10.24	13.02	0.0*	557.32
10/24/77	31	0.0*	14.93	31.33	1028.92
12/12/77	27	14.14	43.85	148.14	390.82

*below minimum detectable limits

(continued)

Appendix B (continued)

SKUNK CREEK BELOW ELIM CREEK

Date	Turbidity (FTU)	Nitrite µg/l	Nitrate µg/l	Ortho-Phosphate µg/l	Total Phosphorus µg/l
8/3/76	43	0.0*	0.0*	0.0*	44.4
9/7/76	30	0.0*	12.34	0.0*	38.8
9/27/76	108	0.0*	0.0*	0.0*	248.61
10/11/76	27	0.0*	0.0*	0.0*	49.49
11/2/76	50	0.0*	0.0*	0.0*	217.81
3/31/77	89	0.0*	0.0*	89.12	829.59
4/18/77	25	0.0*	12.73	535.57	705.21
5/9/77	10	0.0*	38.2	76.71	434.94
6/6/77	21	0.0*	26.1	---	---
6/20/77	45	0.0*	32.8	---	---
8/1/77	66	0.0*	14.24	388.27	626.29
8/29/77	35	0.0*	22.74	69.32	---
9/12/77	42	0.0*	12.74	30.08	924.39
10/3/77	17	0.0*	17.08	57.02	376.93
10/24/77	22	0.0*	12.86	40.65	1168.79
12/12/77	14	0.0*	37.18	45.6	337.09
3/29/78	43	52.35	250.97	160.89	676.47
4/17/78	194	---	47.33	101.17	---
5/9/78	220	---	---	105.86	---
5/11/78	56	---	---	432.70	---
5/16/78	22	---	---	1013.96	---
5/23/78	22	---	---	362.36	---

*below minimum detectable levels

(continued)

Appendix B (continued)

SKUNK CREEK AT HANSON DAM

Date	Turbidity (FTU)	Nitrite µg/l	Nitrate µg/l	Ortho-Phosphate µg/l	Total Phosphorus µg/l
8/3/76	4	0.0*	60.40	0.0*	42.8
9/7/76	dry	stream	bed		
9/27/76	dry	stream	bed		
10/11/76	dry	stream	bed		
4/18/77	10	0.0*	126.93	49.96	472.12
5/9/77	4	12.2	26.2	91.89	213.42
6/6/77	7	0.0*	17.9	---	---
6/20/77	5	0.0*	26.8	---	---
8/1/77	11	0.0*	0.0*	216.37	596.12
8/29/77	8	0.0*	18.73	93.93	---
9/12/77	8	0.0*	0.0*	---	1160.54
10/3/77	30	0.0*	24.98	160.69	75.51
10/24/77	10	0.0*	13.04	0.0*	53.91
12/12/77	15	0.0*	22.63	0.0*	274.4

*below minimum detectable levels

(continued)

Appendix B (continued)

SKUNK CREEK ABOVE HANSON DAM

Date	Turbidity (FTU)	Nitrite μg/l	Nitrate μg/l	Ortho-Phosphate μg/l	Total Phosphorus μg/l
8/3/76	33	0.0*	14.17	0.0*	60.3
9/7/76	22	0.0*	13.4	0.0*	117.6
9/27/76	25	0.0*	0.0*	0.0*	78.53
10/11/76	27	0.0*	0.0*	0.0*	67.55
11/2/76	26	0.0*	0.0*	0.0*	173.12
3/31/77	26	0.0*	0.0*	58.15	293.76
4/18/77	21	0.0*	56.38	59.03	253.27
5/9/77	12	0.0*	40.2	---	442.53
6/6/77	13	0.0*	24.8	---	---
6/20/77	35	0.0*	55.2	---	---
8/1/77	61	0.0*	13.56	246.52	610.95
8/29/77	35	0.0*	17.81	131.59	---
9/12/77	28	0.0*	0.0*	0.0*	508.43
10/3/77	21	0.0*	12.16	14.09	116.62
10/24/77	25	0.0*	0.0*	0.0*	99.79
12/12/77	13	13.53	39.0	0.0*	516.19

*below minimum detectable levels

APPENDIX C. Turbidity and total bacterial, fungal, and fecal coliform counts from December, 1976 through May, 1978 in Little Balsam, Empire, and Skunk Creeks.

LITTLE BALSAM CREEK

Date	Turbidity (FTU)	Bacteria/ml	Fungi/ml	Fecal Coliform Bacteria/ 100 ml
12/14/76	4	1,400	---	---
4/18/77	8	1,660	6500	---
5/9/77	3	1,420	---	---
6/6/77	3	925	---	---
6/20/77	3	3,200	34	---
8/1/77	3	224	300	114
8/29/77	5	102	175	---
10/3/77	3	910	13	2
10/24/77	4	1,090	48	---
11/3/77	4	1,050	---	---
11/14/77	3	220	---	3
12/1/77	3	1,250	---	---
12/12/77	3	650	---	0
1/25/78	4	950	51	0
3/29/78	18	15,600*	670	3
4/10/78	25	610	310	0
4/17/78	4	860	14	0
5/2/78	4	90	16	9
5/9/78	21	5,480	120	18
5/11/78	7	380	15	5
5/16/78	4	510	29	2
5/23/78	4	120	TNTC**	13

* High number due to spring runoff (not averaged in)
**Too numerous to count

(continued)

Appendix C (continued)

EMPIRE CREEK

Date	Turbidity (FTU)	Bacteria/ml	Fungi/ml	Fecal Coliform Bacteria/ 100 ml
12/14/76	3	TNTC**	---	---
4/18/77	6	1,200	5900	---
5/9/77	2	1,280	---	---
6/6/77	2	TNTC**	---	---
6/20/77	2	13,600*	35	---
8/1/77	2	860	300	134
8/29/77	4	440	77	---
10/3/77	3	560	5	5
10/24/77	2	640	36	---
11/3/77	4	900	---	---
11/14/77	2	400	---	6
12/1/77	2	1,220	---	---
1/25/78	4	750	71	2
3/29/78	7	4,600	925	5
4/10/78	25	840	505	4
4/17/78	3	880	12	0
5/2/78	6	90	13	1
5/9/78	12	2,800	200	5
5/11/78	6	200	23	2
5/16/78	4	340	77	7
5/23/78	4	50	TNTC**	6

* High counts due to runoff from heavy rainfall
** Too numerous to count

(continued)

Appendix C (continued)

SKUNK CREEK

Date	(FTU)	Bacteria/ml	Fungi/ml	Fecal Coliform Bacteria/ 100 ml
12/14/76	45	680	---	---
4/18/77	25	TNTC**	TNTC**	---
5/9/77	10	1,060	---	---
6/6/77	21	TNTC**	---	---
6/20/77	45	5,800	42	---
8/1/77	66	8,000	650	1030
8/29/77	35	660	150	---
10/3/77	17	520	33	12
10/24/77	22	770	67	---
11/3/77	48	1,210	---	---
11/14/77	26	1,260	---	56
12/1/77	19	1,800		
12/12/77	15	970	---	---
1/25/78	34	960	65	2
3/29/78	43	15,200*	980	2
4/10/78	194	2,270	2200	325
4/17/78	34	2,040	41	0
5/2/78	30	230	45	232
5/9/78	220	7,520	TNTC**	55
5/11/78	56	9,100	32	28
5/16/78	22	1,280	35	178
5/23/78	22	240	TNTC**	19

* High count due to spring runoff-not used in averaging
**Too numerous to count

APPENDIX D. Summary of average number of macroinvertebrates 0.092 m^{-2} for all sampling periods. Pool averages, riffle averages, and the combined pool-riffle average are included.

	Per 1 Early Sept 1975	Per 2 Late Sept 1975	Per 3 Oct 1975	Per 4 Nov 1975	Per 5 June 1976	Per 6 Aug 1976	Per 7 Oct 1976	Per 8 June 1977	Per 9 Aug 1977	Per 10 Nov 1977
Site 1										
pool	17.0	94.0	78.0		55.0					
riffle	---	---	---		---					
total	34.0	63.7	52.2		39.8					
Site 2										
pool	10.0	71.3	122.0							
riffle	---	---	---							
total	11.5	69.6	115.2							
Site 3										
pool	5.7	66.3	28.3							
riffle	---	---	---							
total	10.8	37.7	17.0							
Site 4										
riffle	---	---	---	---	---	---	---	---	---	---
pool	6.0	23.7	24.3	4.0	8.3	15.7	40.3	210.0	39.0	29.0
total	6.7	21.7	25.0	5.7	6.5	15.8	45.3	105.0	48.7	17.0
Site 5										
riffle	176.3	674.7	381.3	---	74.0	68.3	98.7	102.3	117.7	10.7
pool	52.3	172.3	47.3	8.0	27.3	5.7	9.0	85.7	36.7	31.0
total	124.8	417.5	214.0	5.8	50.7	37.0	53.8	94.0	72.7	12.1

(continued)

Appendix D (continued)

	Per 1 Early Sept 1975	Per 2 Late Sept 1975	Per 3 Oct 1975	Per 4 Nov 1975	Per 5 June 1976	Per 6 Aug 1976	Per 7 Oct 1976	Per 8 June 1977	Per 9 Aug 1977	Per 10 Nov 1977
Site 6										
pool	21.6	84.0	145.0							
riffle	141.5	528.5	253.0							
total	151.5	306.25	199.0							
Site 7										
pool	180	4.7	24.3							
riffle	299.7	318.7	255.7							
total	276.2	161.7	140.0							
Site 8										
riffle	299.7	893.0	305.7	79.3	269.3	1074.3	386.0	235.3	509.3	89.3
pool	180.0	69.0	210.7	62.7	142.3	361.3	63.0	60.7	454.3	31.0
total	276.2	480.8	255.0	71.0	192.0	715.0	224.5	147.8	481.8	60.2
Site 9										
riffle	114.0	505.0	181.3	180.0	528.3	788.0	693.3	1194.7	1002.0	61.7
pool	85.0	82.0	1632.0	24.7	56.0	412.3	89.0	150.3	424.7	27.7
total	99.5	293.5	906.7	102.3	292.2	600.2	391.2	672.5	712.2	44.7
Site 10										
riffle	40.0	159.0	143.3	539.7	335.7	254.3	331.7	68.3	404.7	262.7
pool	60.0	27.0	43.3	396.3	66.7	46.3	93.7	45.7	514.7	13.7
total	50.0	93.0	93.0	471.0	201.0	150.3	212.7	57.0	504.7	138.2

(continued)

Appendix D (continued)

	Per 1 Early Sept 1975	Per 2 Late Sept 1975	Per 3 Oct 1975	Per 4 Nov 1975	Per 5 June 1976	Per 6 Aug 1976	Per 7 Oct 1976	Per 8 June 1977	Per 9 Aug 1977	Per 10 Nov 1977
Site 11										
riffle	458.7	163.7	501.0	354.3	678.0	301.3	557.7	937.7	422.3	122.0
pool	115.0	1295.7	317.3	200.3	84.0	77.0	76.3	240.0	797.7	64.7
total	282.3	440.2	409.2	277.3	382.8	189.2	317.0	588.8	610.0	93.3
Site 12										
riffle	---	---	---	---	116.3	---	---	124.3	408.3	32
pool	---	---	---	---	208.3	553.0	---	373.3	71.7	55.7
total	---	---	---	---	162.3	553.0	---	248.8	240.0	43.8
Site 13										
riffle	379.7	567.3	490.7	---	410.7	667.3	220.7	155.7	595.3	154.0
pool	88.7	195.3	53.7	---	38.7	24.7	47.0	113.0	168.0	19.7
total	207.5	334.2	272.2	---	224.7	346.0	133.8	134.3	381.7	86.8

APPENDIX E. Total number of taxa encountered at sampling sites during 1975, 1976 and 1977.

	1975	1976	1977
Site 4			
riffle	---	---	---
pool	32.0	18.0	40.0
total	42.0	21.0	47.0
Site 5			
riffle	63.0	40.0	44.0
pool	39.0	26.0	31.0
total	79.0	46.0	52.0
Site 8			
riffle	67.0	58.0	65.0
pool	51.0	57.0	59.0
total	79.0	80.0	81.0
Site 9			
riffle	55.0	62.0	80.0
pool	56.0	49.0	62.0
total	77.0	76.0	96.0
Site 10			
riffle	49.0	64.0	59.0
pool	41.0	44.0	54.0
total	67.0	73.0	74.0
Site 11			
riffle	73.0	63.0	62.0
pool	55.0	51.0	60.0
total	97.0	82.0	78.0
Site 12			
riffle	---	32.0	51.0
pool	---	76.0	45.0
total	---	85.0	61.0
Site 13			
riffle	65.0	56.0	68
pool	50.0	43.0	51
total	84.0	72.0	78

APPENDIX F. Summary of Shannon Weaver diversity indices for each sampling period, 1975-1977.

	Per 1 Early Sept 1975	Per 2 Late Sept 1977	Per 3 Oct 1975	Per 4 Nov 1975	Per 5 June 1976	Per 6 Aug 1976	Per 7 Oct 1976	Per 8 June 1977	Per 9 Aug 1977	Per 10 Oct 1977
Station 4										
riffle	---	---	---	---	---	---	---	---	---	---
pool	2.324	3.584	3.274	3.022	2.192	0.780	1.003	3.331	2.244	1.566
total	3.176	2.666	3.317	3.921	1.788	0.585	0.808	3.331	2.731	1.961
Station 5										
riffle	1.705	2.758	3.441	---	3.637	3.357	3.293	3.300	3.257	2.496
pool	3.642	2.899	2.288	3.653	3.058	1.086	3.302	2.292	3.353	3.766
total	2.839	3.403	3.742	3.729	3.839	3.544	3.560	3.442	3.711	3.783
Station 8										
riffle	2.780	3.282	3.465	4.268	2.743	3.140	3.049	3.065	4.304	3.285
pool	0.792	3.828	3.659	3.272	3.449	2.368	3.076	4.232	3.879	3.591
total	1.641	3.490	3.366	4.598	3.525	3.523	3.455	3.579	4.394	3.763
Station 9										
riffle	2.568	3.432	3.530	3.970	3.607	3.229	3.051	2.078	3.764	4.164
pool	3.431	3.937	3.817	3.688	2.995	2.810	3.787	3.103	3.842	3.331
total	3.362	3.740	3.812	4.123	3.934	3.654	3.404	2.562	4.149	4.196
Station 10										
riffle	2.017	2.679	2.587	3.109	2.751	2.451	2.700	3.840	3.011	2.378
pool	3.134	3.494	3.458	2.117	3.307	2.738	3.568	3.325	2.699	3.654
total	3.319	3.049	3.123	2.992	3.271	2.960	3.329	4.333	3.245	2.599

(continued)

Appendix F (continued)

	Per 1 Early Sept 1975	Per 2 Late Sept 1975	Per 3 Oct 1975	Per 4 Nov 1975	Per 5 June 1976	Per 6 Aug 1976	Per 7 Oct 1976	Per 8 June 1977	Per 9 Aug 1977	Per 10 Oct 1977
Station 11										
riffle	3.256	3.313	4.041	3.636	---	4.096	3.459	2.913	4.104	3.253
pool	3.148	2.541	2.858	2.774	3.998	3.774	3.770	3.631	3.684	3.424
total	3.750	4.549	4.321	3.721	3.700	4.466	3.906	3.624	3.984	3.677
Station 12										
riffle	---	---	---	---	3.520	---	---	3.745	3.635	3.931
pool	---	---	---	---	4.598	3.909	---	2.654	3.791	3.752
total	---	---	---	---	4.767	3.909	---	3.226	3.892	4.347
Station 13										
riffle	2.474	3.865	3.899	---	3.399	3.287	2.812	3.752	3.741	3.971
pool	3.548	2.310	3.463	---	3.292	3.924	3.512	3.618	4.071	3.459
total	3.165	4.098	4.142	---	3.570	3.421	3.474	4.022	4.195	4.149

APPENDIX G

GENERIC LIST OF MACROINVERTEBRATES ENCOUNTERED IN THE NEMADJI RIVER WATERSHED, INCLUDING THEIR FUNCTIONAL GROUP

Plecoptera	
Pteronarcidae	
Pteronarcys	shredder
Nemouridae	
Amphinemura	shredder
Nemoura	shredder
Leuctridae	
Leuctra	shredder
Zealeuctra	shredder
Capniidae	
Allocapnia	shredder
Paracapnia	shredder
Taeniopterygidae	
Taeniopteryx	shredder
Perlidae	
Acroneuria	predator
Paragnetina	predator
Phasganophora	predator
Perlinella	predator
Perlodidae	
Isoperla	predator
Chloperlidae	
Hastanerla	predator
Alloperla	predator
Ephemeroptera	
Siphlonuridae	
Isonychia	filter feeder
Ameletus	collector
Acanthametropus	predator
Heptageniidae	
Heptagenia	collector
Rhithrogena	collector
Stenonema	collector
Stenacron	collector
Epeorus	collector
Baetidae	
Baetis	collector
Centroptilum	collector
Cloeon	collector
Heterocloeon	collector
Paracloeodes	collector
Pseudocloeon	collector
Leptophlebiidae	
Habrophlebia	collector
Leptophlebia	collector

Paraleptophlebia	collector
Choroterpes	collector
Ephemerellidae	
Ephemerella	collector
Caenidae	
Caenis	collector
Brachycercus	collector
Ephemeridae	
Ephemera	collector
Hexagenia	collector
Baetiscidae	
Baetisca	collector
Tricorythidae	
Tricorythodes	collector
Odonata	
Gomphidae	
Gomphus	predator
Ophiogomphus	predator
Aeshnidae	
Boyeria	predator
Hemiptera	
Belostomatidae	
Belostoma	predator
Corixidae	predator
Mesoveliidae	
Mesovelia	predator
Trichoptera	
Philopotamidae	
Dolophilodes	collector
Chimarra	collector
Wormaldia	
Psychomyiadae	
Lype	collector
Psychomyia	collector
Polycentropodidae	
Cyrnellus	predator
Neureclipsis	filter
Nyctiophylax	predator
Phylocentropus	filter
Polycentropus	predator
Hydropsychidae	
Cheumatopsyche	filter
Hydropsyche	filter
Rhyacophilidae	
Rhyacophilia	predator
Glossosomatidae	
Agapetus	scraper
Glossosoma	scraper
Protoptila	scraper
Hydroptilidae	
Hydroptila	scraper
Ochrotrichia	collector

<u>Orthotrichia</u>	collector
<u>Agraylea</u>	collector
<u>Leucotrichia</u>	collector
Brachycentridae	
<u>Micrasema</u>	shredder
<u>Brachycentrus</u>	filter
Phryganeidae	
<u>Ptilostomis</u>	shredder
Phryganeidae	
<u>Ptilostomis</u>	shredder
Limnephilidae	
<u>Hesperophylax</u>	shredder
<u>Hydatophylax</u>	shredder
<u>Pseudostenophylax</u>	shredder
<u>Pyconopsyche</u>	shredder
<u>Onocosmoecus</u>	shredder
Lepidostomatidae	
<u>Lepidostoma</u>	shredder
Molannidae	
<u>Molanna</u>	scraper
Helicopsychidae	
<u>Helicopsyche</u>	scraper
Leptoceridae	
<u>Ceraclea</u>	collector
<u>Oecetis</u>	predator
<u>Nectopsyche</u>	shredder
<u>Setodes</u>	collector
Megaloptera	
Sialidae	
<u>Sialis</u>	predator
Coleoptera	
Dytiscidae	
<u>Liodessus</u>	predator
<u>Hygrotus</u>	predator
<u>Illybius</u>	predator
<u>Agabus</u>	predator
<u>Hydroporus</u>	predator
Hydrophilidae	
<u>Anacaena</u>	shredder
<u>Hydrobius</u>	shredder
<u>Helophorus</u>	shredder
Gyrinidae	
<u>Gyrinus</u>	predator
<u>Dineutus</u>	predator
Elmidae	
<u>Dubiraphia</u>	collector
<u>Microcylloepus</u>	collector
<u>Optioservus</u>	collector
<u>Stenelmis</u>	collector
Dryopidae	
<u>Helichus</u>	scraper

Diptera	
Empididae	predator
Rhagionidae	
Atherix	predator
Stratiomyidae	
Sciomyza	collector
Tipulidae	
Tipula	shredder
Antocha	collector
Dicranota	predator
Pedicia	predator
Limnophila	predator
Pilaria	predator
Hexatoma	predator
Limonia	shredder
Helius	collector
Psuedolimnophila	
Prionocera	shredder
Erioptera	collector
Chaoboridae	
Chaoborus	predator
Ceratopogonidae	
Palpomyia	predator
Dasyhelia	collector
Dixidae	
Dixa	collector
Dixella	collector
Simulidae	
Prosimulium	filter
Eusimulium	filter
Silmulium	filter
Cnephia	filter
Tabanidae	
Chrysops	collector
Tabanus	predator
Psychodidae	
Pericoma	collector
Chironomidae	
Tanypodinae	
Procladius	predator
Tanypus	predator
Psectrotanypus	collector
Clinotanypus	predator
Coelotanypus	predator
Natarsia	predator
Ablabesmyia	predator
Pentaneura	predator
Labrundinia	predator
Nilotanypus	predator
Guttipelopia	predator
Zavrelimyia	predator
Conchapelopia	predator
Larsia	predator

Diamesinae	
Potthastia	collector
Prodiamesa	collector
Orthocladinae	
Corynoneura	collector
Thienemanniella	collector
Symbiocladius	parasite
Psuedosmittia	collector
Epoicocladius	collector
Diplocladius	collector
Rheocricotopus	collector
Psectrocladius	collector
Cardiocladius	predator
Brillia	shredder
Trissocladius	collector
Plecopteracoluthus	collector
Eukiefferiella	collector
Heterotrissocladius	collector
Parametriocnemus	collector
Smittia	collector
Orthocladius	collector
Cricotopus	collector
Chironominae	
Stempellina	collector
Paratanytarsus	collector
Cladotanytarsus	collector
Rheotanytarsus	filterer
Micropsectra	collector
Tanytarsus	collector
Stictochironomus	collector
Lauterborniella	collector
Microtendipes	collector
Paratendipes	collector
Cryptocladopelma	
Demicryptochironomus	collector
Paracladopelma	
Harnischia	collector
Parachironomus	predator
Cryptochironomus	predator
Stenochironomus	collector
Polypedilum	collector
Nilothauma	
Endochironomus	collector
Phaenopsectra	scraper, collector
Psuedochironomus	collector
Xenochironomus	predator
Dicrotendipes	collector
Einfeldia	collector
Glyptotendipes	shredder, collector
Chironomus	collector, shredder
Kiefferulus	collector
Paralauterborniella	collector

Annelida
- Oligochaeta
- Hirudinea

Nematoda

Hydracarina

Gastrapoda
- Ancylidae

Pelecypoda
- Sphaeridae

Amphipoda
- Hyallela
- Gammarus

Isopoda

APPENDIX H

FISH SPECIES COMPOSITION BY SITE WITH RELATIVE ABUNDANCE

	SITE 1	4	5	8	9	10	11	12	13
Percidae									
Perca flavescens (yellow perch)	U	U	R	N	N	N	N	N	N
Stizostedion vitreum vitreum (walleye)	SA	R	U	N	N	N	N	N	N
Percina caprodes (logperch)	U	R	C	N	N	N	N	N	N
Etheostoma nigrum (johnny darter)	R	R	C	R	N	N	C	C	U
Salmonidae									
Salmo trutta (brown trout)	U	R	U	C	R	C	R	N	R
Salmo gairdneri (rainbow trout)	U	R	U	R	R	N	N	N	N
Salvelinus fontinalis (brook trout)	N	N	U	C	A	A	N	N	N
Catostomidae									
Catostomus catostomus (longnose sucker)	SA	SA	SA	N	N	N	N	N	N
Catostomus commersoni (white sucker)	SA,C	SA	SA,C	U	U	N	C	C	C
Moxostoma anisurum (silver redhorse)	SA,C	SA	SA,C	N	N	N	N	N	N
Moxostoma macrolepidotum (shorthead redhorse)	SA,C	SA	SA,C	N	N	N	N	N	N
Ictaluridae									
Ictalurus melas (black bullhead)	A	N	N	N	N	N	N	N	N
Noturus gyrinus (tadpole madtom)	C	N	N	N	N	N	N	N	N
Noturus flavus (stonecat madtom)	U	N	C	N	N	N	N	N	N
Cyprinidae									
Semotilus atromaculatus (creek chub)	U	C	C	C	N	R	A	A	A
Nocomis biguttatus (hornyhead chub)	U	C	C	N	N	N	N	N	N
Cyprinus carpio (carp)	A	N	N	N	N	N	N	N	N
Hybognathus hankinsoni (brassy minnow)	R	R	U	N	N	N	R	N	R
Notropis atherinoides (emerald shiner)	SA	SA	SA	N	N	N	N	N	N

(continued)

Fish Species Composition by Site with Relative Abundance (continued)

	SITE 1	4	5	8	9	10	11	12	13
Notropis cornutus (common shiner)	U	C,SA	C	R	N	N	C	R	C
Notropis heterolepis (blacknose shiner)	U	R	U	N	N	N	N	N	N
Notropis stramineus (sand shiner)	R	R	R	N	N	N	N	N	N
Pimephales promelas (fathead minnow)	R	N	N	N	N	N	R	R	R
Rhinichthys cataractae (longnose dace)	R	U	C	A	U	N	C	C	C
Rhinichthys atratulus (vlacknose dace)	R	U	C	C	N	N	A	A	A
Semotilus margarita (pearl dace)	R	U	U	N	N	N	U	U	U
Osmeridae									
Osmerus mordax (rainbow smelt)	SA	SA	SA	N	N	N	N	N	N
Centrarchidae									
Ambloplites rupestris (rock bass)	C	U	C	N	N	N	N	N	N
Pomoxis nigromaculatus (black crappie)	R	N	R	N	N	N	N	N	N
Percopsidae									
Percopsis omiscomaycus (trout-perch)	U	U	C	N	N	N	C	R	C
Esocidae									
Esox lucius (northern pike)	U	U	R	N	N	N	N	N	N
Gadidae									
Lota lota (burbot)	SA	U	U	N	N	N	N	N	N
Gasterosteidae									
Culaea inconstans (brook stickleback)	R	N	R	N	A	N	R	R	R

(continued)

Fish Species Composition by Site with Relative Abundance (continued)

	SITE 1	4	5	8	9	10	11	12	13
Umbridae									
Umbra limi (central mudminnow)	U	U	R	N	N	N	R	R	R
Cottidae									
Cottus bairdi (mottled sculpin)	R	R	R	A	C	C	A	A	C

A - abundant
SA - seasonally abundant
C - common
U - uncommon
R - rare
N - not present

APPENDIX I. Population size (fish hec^{-1}) and biomass (kg hec^{-1}) in sites on the Nemadji River and Little Balsam, Empire, Skunk and Elim Creeks. Biomass estimates appear immediately below population estimates.

Site	10/75	5/76	6/76	8/76	9/76	10/77	Avg.
4	866	974	1507	1629	1522	---	1300
	7.7	157.8	13.0	13.0	44		19.4
5	133	*	792	3932	3180	8400	3287
	2.4		6.4	35.2	39.7	22.5	21.2*
8	7095	2350	5631	11973	27405	1064	9252
	98.6	42.8	178.2	56.8	37.3	9.0	70.5
9	8202	1968	4593	2297	4183	3280	4087
	14.9	56.8	70.2	13.3	73.6	47.3	46.0
10	6561	2870	6234	10088	14353	3937	7340
	109.7	55.2	134.9	229.7	134.9	56.1	120.1
11	13887	5358	3445	---	10411	9623	9545
	81.8	92.3	38.5		112.4	9.1	66.7
12	---	13731	7677	8398	---	22703	13127
		223.8	35.0	82.6		51.4	98.2
13	7669	6394	12788	7767	6662	3639	7487
	195.2	61.7	99.2	39.7	99.7	116.9	96.7

*does not include 5/76 collection when spawning suckers were very numerous.

VEGETATION AND RED CLAY SOIL STABILITY

by

Lawrence A. Kapustka, Donald W. Davidson and Rudy G. Koch*

*Project Associate, CLSES; Associate Professors-Biology; UW-Superior.

INTRODUCTORY REMARKS

Vegetation effectively reduces both surface and slump erosion by intercepting precipitation, reducing the velocity of precipitation, retaining soil particles and reinforcing soil structure (1, 2). Among the most significant features in this regard are (a) an increase in the shear strength of soils as a result of reinforcement by roots and (b) soil arching, the transfer of stress across a potential failure surface in the soil (2). Significant correlations between tree cover and slope stability have been developed in several field studies (3, 4, 5, 6, 7). Swanston (8) found an apparent cohesion and shear strength that is not reflected by the physical properties of Karta soils in southeastern Alaska. His study of root deterioration following clearcutting indicated that the contribution by tree roots to soil shear strength diminished within 3-5 years. This rate of decay coincided with the observed lag time for landslide acceleration following the harvest.

Currently, vegetation is used effectively to reduce erosion along roadsides and other construction situations in which the erosional forces are minimal once construction is completed and the initial ground cover has developed (9, 10).

Although these plant properties related to erosion abatement are accepted generally, the relative contributions of each applied to a specific problem are speculative. Studies performed during the past 2-1/2 years have sought to define the capacity of vegetation to moderate erosion of the red clay zone of the Nemadji River Basin which empties into western Lake Superior. These investigations have had 3 main thrusts: 1) the desciption of the vegetation, pre-settlement and contemporary; 2) the influence of the vegetation on soil water content and 3) the distribution and strength of plant roots in the region.

The Nemadji Basin

The Nemadji River drains an area of 1200 km^2 (460 mi^2) in Douglas County, northwestern Wisconsin and Carlton and Pine Counties, northeastern Minnesota (Figure 1). This stream carries a heavy burden of eroding clay soil (5.4 x 10^5 mton annually) from this relatively young landscape and is a major contributor of red clay in Lake Superior (11).

Soils

The soils of the Nemadji River Basin are derived from glacial till and lake sediments. The clays of lacustrine origin, the predominant soil type, are of the montmorillonite type ≤ 2 μ diameter. Beach sands, unsorted sand, silt and clay from glacial drift comprise the remaining soil components. Generally, the lacustrine clay zones are well drained whereas the glacial till zones are poorly drained (12, 13).

The clays, remarkably uniform throughout the study area, have a bulk density ($g \cdot cm^{-3}$) ranging between 0.94 and 1.12 with a mean of 1.05. The plastic limits range from 20-30%. The liquid limits typically range from 40-80% (14). Auger borings reveal relatively uniform moisture content >40% for depths greater than 3 m.

Climate

The climate is typical of the western Great Lakes area. The following table summarizes recent climatic data for three stations in or near the basin.

Climate Summary

	Superior, WI	Cloquet, MN	Moose Lake, MN
Precipitation (in.)			
Average Annual	27.9	29.1	27.5
Temperature (F.)			
Average daily maximum	50.2	50.4	52.4
Average daily minimum	30.8	27.0	28.0
Average January maximum	22.2	18.7	20.8
Average January minimum	2.9	-2.8	-2.2
Average July maximum	77.7	80.2	81.0
Maximum	105	105	99
Minimum	-37	-45	-49
Average frost free days	173	167	169

About 3.5 inches of precipitation per month occurs from May to August, and 1 inch or less during December through February. The growing season is relatively short and the average temperatures are cool.

Weather data for the Little Balsam subbasin appears to fluctuate more than at the nearest official weather monitoring site, the Duluth International Airport. For the months May-October rainfall in the Little Balsam sites was 242.6 mm for 1976 and 741.2 mm for 1977 (17). At Duluth total rainfall amounts for the same periods were 332.0 mm and 604.8 mm respectively. The 30 years mean precipitation for the period is 526.6 mm (11). For the western Lake Superior region the typical annual evapotranspiration potential is less than the expected annual precipitation. The probability of evapotranspiration exceeding precipitation is only 1 year in 50 (19).

SUMMARY

Vegetation

Presettlement: As revealed from survey records of 1860 the Nemadji Basin as a whole was dominated by white pine (*Pinus strobus* L.) with an importance percentage of 27.2. Almost one-fourth of the white pine were 60 cm DHB or larger, a size ummatched by any other tree in the forest. Spruce (*Picea* spp.), tamarack (*Larix laricina* Du Roi) and birch (*Betula* spp.) were other species contributing significantly to the character of the forests. As a synthetic unit, the forests were moderately dense with 187 trees·ha^{-1}. The average diameter of the trees was near 28 cm.

Major communities determined from the survey records included flood plain forest types exemplified by ash (*Fraxinus* spp.); upland and ravine forests indicated by significantly larger tree diameters in the ravines; and on a large scale white pine and tamarack forests. The white pine community was restricted chiefly to the elevations <330 m which approximates the lake bed of glacial Lake Duluth. Similarly tamarack tended to occupy the sandy, poorly drained soils outside the former lake bed.

Contemporary Vegetation: Human impact on the vegetation of this region has been significant since the logging activities of the last century. After the forest cover had been removed, much of the area was converted to agricultural use. This usage seemingly reached its maximum extent during the 1920's and 1930's. Gradually, agricultural interests have diminished and much of the area is reverting to forest cover. Genera-ly the vegetation pattern of the Nemadji Basin as a whole shows evidence of disturbance.

Vegetation and Soil Moisture

The various species and vegetation cover types have significant effects on the redistribution of rainfatl as it moves through the canopy. The open canopy species such as aspen (*P. tremuloides*), and white birch (*B. papyriferu*) have the least influence wheras fir and spruce have the greatest influence on intercepting rainfall. The greatest importance of this is in reducing the impact of rain on the soil surface. Particularly when the tree surfaces have become dry do the dense canopy species reduce the amount of moisture reaching the soil surface.

The measures of soil moisture indicate major differences in soil moisture conditions among the various vegetative covers. Grassed areas, including pasture and abandoned agricultural fields, and aspen experienced the greatest drying of the soil. However during years with normal

Table 1. Mean root biomass of Skunk Creek Transect No. 6 (gram oven dry weight rounded to nearest gram)

	Root Diameter (mm)												
Depth	<0.5	0.5-0.99	1.0-1.99	2.0-2.99	3.0-3.99	4.0-4.99	5.0-9.99	10.0-14.99	15.0-19.99	20.0-24.99	25.0-29.99	≥30	Totals
0-10 cm	159	105	46	29	22	24	39	20	45	34	80	198	807
10-20 cm	40	42	28	15	12	12	47	32	30	74	11	40	327
20-30 cm	9	20	18	9	10	8	30	12	10	0	31	0	160
30-40 cm	6	10	9	11	4	3	14	12	0	0	0	0	71
40-50 cm	4	7	5	5	6	4	11	3	0	0	14	0	62
Totals	221	187	107	71	56	51	142	78	86	109	137	239	1489

Table 2. Mean root biomass of Little Balsam Transect 5 (grams oven dry weight rounded to nearest gram)

	Root Diameter (mm)												
Depth	<0.5	0.5-0.99	1.0-1.99	2.0-2.99	3.0-3.99	4.0-4.99	5.0-5.99	10.0-14.99	15.0-19.99	20.0-24.99	25.0-29.99	≥29.9	Total
0-10 cm	26.1154	11.0469	29.8678	39.8549	17.5660	15.6290	2.7817	0	0	0	0	0	142.8617
10-20 cm	2.0617	2.2247	8.0153	26.9410	6.6026	2.2124	10.1146	1.4050	0	0	0	0	59.5773
20-30 cm	1.1529	2.0415	8.2147	31.6661	5.8784	0.4987	3.3887	1.7715	0	0	0	0	54.6125
30-40 cm	0.5304	0.8948	5.1335	25.9891	6.1627	0.2030	0.0550	0	0	0	0	0	38.9585
40-50 cm	0.3553	0.8342	4.9019	24.6179	7.8969	2.0798	0	0	0	0	0	0	40.6860
Totals	30.2057	17.0421	56.1332	149.0690	44.1066	20.6229	16.3700	3.1765	0	0	0	0	336.6960

These data do not include roots from the soil subsample.

amounts of precipitation the soils of all cover types remain at near field capacity for the majority of the summer.

The measures of red clay consistency demonstrate a rather narrow range of soil stability with respect to soil moisture content. Our measures of the permanent wilting point of the soils indicate that plants can draw down the soil water content to 11.8±0.3% thereby inducing soil fracturing. Large fissures (>2 cm wide and several meters long to depth of 15 cm or more) were common in the grassy areas in 1976. Many of these fissures remained throughout 1977 and 1978. During wet periods when precipitation exceeds evapotranspiration the soils exceed the liquid limit and are subject to liquid flow.

Vegetation and Soil Stability

Measurements of soil slumping indicates the major activity occurs during the spring thaw period, especially if the soil was wet prior to freeze-up. Plants develop the potential to remove significant amounts of water from the soil only after the expansion of leaves, which in this region occurs in mid to late May. A comparison of the soil moisture conditions of 1976 and 1977 suggest that plants can have a significant draw down of soil moisture only during the drier than normal years. In unusually dry years certain vegetative covers, especially the grass and sparse aspen areas, the soils dry below the plastic limit creating future erosion problems.

Surface Runoff

The volume of runoff in areas with slumping was considerably higher than in stable areas for both grassed and wooded areas and tended to increase logarithmically with increasing amounts of precipitation.

The sediment load was extremely variable, especially in the grassed areas. Again major differences are apparent between the slumped and stable areas. The major difference occurred between the grassed and the wooded areas with approximately 10-fold more sediment in the runoff from the grassed areas.

Root Distribution and Root Strength

Trends in root distribution with respect to depth and soil type reflect differences in vegetation cover significant to erosion control. In the wooded clay soils (Table 1) up to 55% of the root mass was found in the upper 10 cm of soil with an additional 20% in the 10-20 cm layer. For smaller roots (i.e. <1 mm diam.) as much as 70% (dry weight basis) occur in the upper 10 cm and 90% in the upper 20 cm of soil.

By comparison, the grassy slopes contain approximately 1/5 to 1/3 as much root mass as the wooded areas (Table 2). Furthermore the upper 10 cm harbor as little as 30% of all roots in the 50 cm profile. Generably the grassed areas have a rather uniform distribution throughout the remainder of the profile. This uniformity appears to result from the distribution of Equisetum rhizomes, while the grass roots diminish rapidly with depth.

These patterns of root distribution and the measure of root tensile strength suggest a significant relationship between erosion activity and certain vegetation types. The major slumping activity occurred in grassed transects and in open aspen dominated transects. The herbaceous areas are characterized by a sparse rooting system and relatively weak roots. The aspen typically has weak roots. Similar transects with a mixture of fir or hazel both which ahve roots significantly stronger than aspen had less slumping activity. Although it is difficult to determine cause-effect relationships from vegetation sampling, the relatively high importance of hazel in the non-slumped areas and its scarcity in the slumped areas may indicate that the stronger hazel roots have been effective in holding the soils of the non-slumped sites.

GENERAL CONCLUSIONS

It appears as if reduction of soil water content by plants may lead to counterproductive results. The vegetation types most effective in soil water depletion are effective only in drier years and then lower the water content of the clay below the plastic limit. Consequently, other vegetation types which tend to have greater amounts of cover, appear to be more effective in reducing erosion due to other factors. Perhaps the most significant factor is the relatively stronger roots of the more advanced successional woody species. Because of the relatively shallow rooting pattern and the relatively weaker roots of the herbaceous plants compared to woody plants, slumping and surface erosion tends to be greater in areas with predominant herbaceous cover. Although no vegetation is expected to abate completely the erosion forces of this geologically young region, woody climax vegetation appears to be most capable of ameliorating the process.

RECOMMENDATIONS

The following guidelines for management of vegetation in the red clay zone are intended to be simple, feasible practices that will lead to significant reduction of erosion.

--On construction sites, vegetation should be established at the earliest opportunity.

- --Where possible, woody species should be phased into the herbaceous cover.

- --Among woody species, the more advanced successional species are preferred, largely due to their greater root strength.

- --Along stream banks and associated drainage areas, soil stability equations should be employed to demarkate the "100-year safe zone." Within this zone, all human activity that arrests or reverts the successional process should be prohibited. This includes logging and unnecessary construction unless these activities are consistant with forest management practices that promote advanced successional stands.

- --In critical erosion sites, the establishment of advanced successional woody vegetation should be actively promoted by acceptable methods of forest management including planting of seedlings, selective cutting, and fertilizer application.

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VEGETATIONAL COVER ANALYSIS

by

R. G. Koch, S. H. Stackler, L. M. Koch, and L. Kapustka*

Vegetation cover, and related factors such as litter and organic content of soil, is known to be important in controlling and/or reducing erosion rates (1). Other factors such as slope, soil particle size, soil chemistry and water content are also important.

This project was designed to provide an analysis of cover on two watersheds in the Nemadji Basin. This, in turn, could be useful in determining locations of specific demonstration projects, serving as a guide in developing practical land management procedures, utilizing present cover capabilities in minimizing red clay erosion and to provide, from the historical record, an indication of cover prior to the settlement of the area.

I. PRESETTLEMENT VEGETATION OF THE NEMADJI RIVER BASIN

Survey Records

Survey records are a source of information about early vegetation. They were written in the field and followed a previously determined plan, thus constituting a well defined sample of the vegetation which can serve as the basis for quantitative and qualitative analysis.

Bourdo (2) discusses the use of the General Land Office survey records in vegetational analysis and provides a good review of problems that may be encountered. The work on the presettlement vegetation of the Nemadji Basin involved examination of surveying records for two states and three counties. Difficulties encountered stemmed from several factors, as described below.

Nomenclature: Correlation of surveyor's tree names with those in use today was not a significant problem. Most names were readily recognizable, though a few were encountered which were initially puzzling. As an example, an entry "Lynn" appears to be similar to "Lind" and "Linde" which must be a reference to Linden (*Tilia americana*), more familiar to us as basswood.

*Associate Professor, Biology; Project Assistant; Project Associate; and Project Specialist, Center for Lake Superior Environmental Studies, University of Wisconsin-Superior 54880.

More troublesome, however, was the usage of names which varied between surveyors. Probably the most obvious example of this was encountered with the birches. The Douglas County (Wisconsin) records typically recognized only birch, rarely distinguishing between the yellow birch (*Betula lutea*) and the paper birch (*B. papyrifera*).

In the Minnesota records nearly all birches were recorded as either yellow birch or paper birch. Because of this uneven treatment, it was not possible to distinguish between the birches in the analytical work.

In a similar fashion, the records available to us did not always distinguish between the pines, spruces and oaks. The identity of a few names, such as "spruce pine" were not established with certainty. These names of uncertain meaning were not common.

Bias undoubtedly crept in when bearing trees were selected for the iron marks. Since (with the exception of beech which was not reported in our area) the surveyors had to remove the bark to mark the bole with a timber scriber, it is likely that trees with loose bark were included more frequently. The relocation of corners would be easier for the field crews if uncommon species were identified, and it is likely that many surveyors tended to do this. Diameters, especially of large trees, were likely to be estimated, as were distances between the trees selected and the corner, particularly when this distance, was great. These estimated distances and diameters tend to show up in the data as rounded numbers, such as 20, 25 or 30 inches, or 40, 50 or 60 links.

Measurement errors were also probable. The most common was the exclusion of the tree's radius in measuring the tree-to-corner distances. When the tree size was large, this could be a significant source of error. Our data suggested relatively small trees, and so the error from this source was thought to be too small to warrant correction.

The records used in this study were obtained from a number of sources, and represent work originally done at different times by different surveyors. A list of the records examined by township follows:

Douglas County, Wisconsin

T46N, R15W William E. Daugherty, Deputy Surveyor 1860

(xeroxed copies of the original)

T45N, R14W	T45N, R15W	T46N, R14W
T47N, R14W	T47N, R15W	T48N, R14W

Data from blueprint records of Douglas County Plat Book, maintained at the Douglas County Historical Museum and/or Zoning Administrator's Office, Douglas County.

Pine County, Minnesota

T45N, R18W	B. F. Jenness, Deputy Surveyor
T45N, R17W	B. F. Jenness, Deputy Surveyor
T45N, R16W	Alex L. Bradley & E. Edward Davies, Deputy Surveyors

Xeroxed copies of 1869 surveyor's line field notes and updated township line notes of Pine County, Register of Deeds Office, Pine County, Minnesota.

Carlton County, Minnesota

T46N, R18W	Milton Nye, Deputy Surveyor
T46N, R17W	Milton Nye, Deputy Surveyor
T47N, R18W	Milton Nye, Deputy Surveyor
T47N, R17W	Milton Nye, Deputy Surveyor

Xeroxed copies of 1858 surveyor's line field notes, kept by Neubert Swanson, Carlton County Surveyor at Moose Lake. Township lines filled in from blueprint records of Carlton County Plat Book, located in Register of Deeds Office, Carlton, Minnesota.

T46N, R16W	T47N, R16W	T48N, R16W
T48N, R17W	T46N, R18W	

All information from blueprint records of the Carlton County Plat Book, Register of Deeds Office, Carlton, Minnesota.

Analysis

Point-centered quadrats of the plotless methods now common in plant ecology were originally derived from procedures used by the early surveyors. As a result, the data contained in the surveying records can be analyzed by standard plotless procedures. However, since the points recorded by the surveyors were not restricted to discrete stands, caution in interpretation is necessary.

Corners at which four trees were recorded provide better data than those at which only two trees were recorded. Because of the limitation inherent in using data from two-tree corners, it was necessary to separate two-tree (2-point) and four-tree (4-point) data. The latter provided estimates of density which are unavailable with two point data.

From the surveying records, tree species, diameter at breast height, and distance from the corner (for four-point corners) as well as the location of the corner were recorded on work sheets from which punched data cards were prepared. These data were subjected to computer analysis to provide Frequency, Density, Dominance, and Importance Percentage measures of the vegetation recorded by the surveyors. A discussion of these procedures is provided by Greig-Smith (3).

By using different combinations of data points, it was possible to summarize the data for each township, the two study basins (Little Balsam Creek and Skunk Creek), for the entire Nemadji Basin, for the area once under the glacial Lake Duluth, and for areas in or out of the deeply eroded stream beds.

Species Distribution: By using the computer, it was possible to identify every corner at which a given species occurred, and to print the number of individuals of a given species at a point corresponding to the location of the corner. Such maps, though somewhat distorted (because of computer printer limitations), indicate the distribution of given species within the basin.

Ordination: Numerous ordination techniques have been developed as a means of displaying or summarizing data of community composition. The ordination can be used to assist in formulating hypotheses or merely to display phytosociological information in graphic form. Frequently an ordination leads to a recognition of relationships that exist between species, populations or community structure and environmental factors.

Among the various techniques of ordination (4) are those which compare communities on the basis of (a) similarity of species present and (b) percentage composition of species in the respective communities. When dealing with extremely diverse habitats, species presence is preferred since it is less subject to sampling error (5). However, in the less diverse habitats such as the Nemadji Basin percentage composition provides discriminations. In this study, the survey data of the vegetation of the Nemadji River Basin (Townships, including both 2-point and 4-point data are considered as communities.) were used to calculate the Bray-Curtis (6) ordination as modified by Gauch and Whittaker (5).

The end points selected were chosen to reflect the geographical distribution of species.

Results

Although the work reported here is a summary of the vegetation as recorded by surveyors, it is not possible to determine, *a priori*, discrete vegetation stands for analysis. As a result, all summaries in the basin included corners representing different vegetation types. The end result is a synthetic picture of the forest without regard to local variation patterns which must have been present. The interpretations must be tempered by the realization that the summaries are based on broad, inclusive categories.

Frequency: In the Nemadji Basin as a whole (Table 1), white pine (*Pinus strobus*) had the highest I.P. (Importance Percentage) value. Nearly one fourth of all of the white pines were 24 in. DBH or larger, a size practically unmatched by any other tree in the forest. However, spruce (*Picea* spp.) occurred with near or greater frequency. Next in significance was tamarack (*Larix laricina*) and birch, if the birch species were grouped (*Betula* spp.). The density of the forest is 75 trees per acre, with an average point to tree distance of 7.3 feet. The average diameter of the trees was near 11 inches.

Table 1. Summary of pre-settlement vegetation of the Nemadji Basin. F = % frequency of points at which species was present; I.P. = Importance Percentage = relative density + relative dominance + relative frequency. (Only species with I.P. >5 reported.)

Species	2 pt.		4 pt.	
	F	I.P.	F	I.P.
Abies balsamea	35.4	9.5	16.4	4.9
Betula papyrifera	20.1	6.1	24.4	9.4
Betula spp.	28.5	8.7	10.5	4.1
Larix laricina	41.4	12.7	24.7	11.0
Picea spp.	50.2	14.4	35.2	13.9
Pinus resinosa	8.2	3.3	9.9	6.3
Pinus strobus	41.4	22.3	38.0	27.2
Populus spp.	17.2	5.6	17.3	6.5
n =	2050		1296	
$\bar{X}$ dbh (in.)	10.7		11.5	
$\bar{X}$ point-to-tree distance (ft.)	n.d.		7.3	
$\bar{X}$ density (trees/acre)	n.d.		75.8	

In comparison with the whole basin, the two study areas, Little Balsam Creek and Skunk Creek watersheds (Table 2) appear to be somewhat different. In the Little Balsam, maple (*Acer saccharum*) is the dominant tree, though white pine has a high I.P. value. The Skunk Creek Basin has white pine as a dominant species with little maple reported. Both areas have tree diameters a bit larger than the basin average, but the sample sizes are too small in both instances to allow firm conclusions about their uniqueness.

Table 2. Summary of pre-settlement vegetation of the Little Balsam Creek and Skunk Creek Watersheds. F = % frequency of points at which species was present; I.P. = Importance Percentage = relative density + relative dominance + relative frequency. (Only species with I.P. >5 reported.)

	LITTLE BALSAM		SKUNK CREEK			
	2 pt.		2 pt.		4 pt.	
Species	F	I.P.	F	I.P.	F	I.P.
Abies balsamea	22.2	5.1	n.r.	n.r.	30.8	9.0
Acer saccharum	77.7	23.8	n.r.	n.r.	7.7	2.0
Betula lutea	n.r.	n.r.	8.3	2.9	23.8	8.0
B. papyrifera	11.1	2.7	25.0	6.0	46.2	21.2
B. spp.	55.6	17.1	n.r.	n.r.	n.r.	n.r.
Fraxinus nigra	n.r.	n.r.	16.7	5.0	n.r.	n.r.
Larix laricina	11.1	2.5	41.7	10.6	23.1	6.8
Picea spp.	22.2	5.7	25.0	6.2	30.7	15.3
Pinus spp.	22.2	9.2	n.r.	n.r.	n.r.	n.r.
Pinus strobus	44.4	21.7	100.0	43.7	53.8	33.5
Populus spp.	n.r.	n.r.	25.0	6.5	7.7	2.2
Thuja occidentalis	11.1	4.5	25.0	7.2	n.r.	n.r.
n =	36		50		52	
$\bar{X}$ dbh (in.)	12.4		14.6		12.8	
$\bar{X}$ point-to-tree distance	n.d.		n.d.		6.0	
$\bar{X}$ density (trees/acre)	n.d.		n.d.		113.3	

When maps of the Nemadji Basin were examined, it appeared that many corners fell into the deeper ravines eroded by small streams. When all corners thus identified were examined as a group in comparison to the corners on the more level lake plane (Table 3), it was apparent that the two areas differed in vegetation. The original hypothesis was that the steep slopes of the ravines generally would be less stable. Disturbance from slumping would occur, resulting in data which would indicate a somewhat younger, smaller forest than the adjacent uplands. Just the opposite was observed, however. The ravine stands apparently consisted of somewhat larger trees and appear to be slightly more dense.

Table 3. Comparison of pre-settlement vegetation between ravine and upland corners of the Nemadji Basin. F = % frequency of points at which species was present; I.P. = Importance Percentage = relative density + relative dominance + relative frequency. (Only species with I.P. >5 reported.)

	RAVINE				UPLAND			
	2 pt.		4 pt.		2 pt.		4 pt.	
Species	F	I.P.	F	I.P.	F	I.P.	F	I.P.
Abies balsamea	59.1	16.5	20.4	6.3	31.8	8.4	15.6	4.6
Betula papyrifera	25.8	8.0	20.4	6.1	19.3	5.8	25.1	10.2
Betula spp.	16.7	4.7	10.2	3.6	30.3	9.4	10.5	4.3
Larix laricina	10.6	2.9	12.2	4.8	46.0	14.2	27.0	12.2
Picea spp.	50.0	14.8	34.7	12.1	50.2	14.3	35.3	14.3
Pinus resinosa	3.0	0.7	4.1	3.1	9.0	3.8	10.9	7.0
Pinus strobus	59.1	28.9	69.4	47.5	38.8	21.3	32.4	22.9
Populus spp.	12.1	4.2	4.1	1.3	17.9	5.8	19.7	7.6
n =	264		196		1786		1100	
$\bar{X}$ dbh (in.)	11.9		14.0		10.6		11.0	
$\bar{X}$ point-to-tree distance (ft.)	n.d.		7.1		n.d.		7.3	
$\bar{X}$ density (trees/acre)	n.d.		79.4		n.d.		75.2	

A final comparison (Table 4) was undertaken to examine the nature of the vegetation within and without the boundary of the former glacial Lake Duluth. From ordination patterns and species distribution maps, there was a strong indication that the 1100 foot contour line formed an approximate boundary between two major vegetational types. Since this same contour line generally marks the uppermost zone of influence of the old lake, corners were separated on the basis of their location in reference to the 1100 contour line. Vegetation in the two areas differ with tamarack the dominant species but nearly equaled in I.P. by spruce and white pine) outside of the old lake bed. Inside, white pine is the major dominant with no near challengers. In addition, the corners outside of the old lake bed influence tended to be smaller and denser, consistent with a tamarack dominated forest type.

Table 4. Comparison of pre-settlement vegetation between corners located inside the 1100 ft. contour line (approximate outer boundary of glacial Lake Duluth) and outside. F = % frequency of points at which species was present; I.P. = Importance Percentage = relative density + relative dominance + relative frequency. (Only species with I.P. >5 reported.)

	Inside (Less) 1100' Contour				Outside 1100' Contour			
	2 pt.		4 pt.		2 pt.		4 pt.	
Species	F	I.P.	F	I.P.	F	I.P.	F	I.P.
Abies balsamea	42.8	11.6	21.8	6.6	27.4	7.2	10.0	2.9
Betula papyrifera	16.7	4.8	21.8	8.5	23.8	7.6	27.3	10.7
Betula spp.	23.1	6.7	8.6	3.1	34.3	11.0	12.7	5.7
Larix laricina	30.3	8.9	19.0	8.2	53.3	16.9	31.3	14.8
Picea spp.	56.1	15.6	35.6	13.8	44.0	13.0	34.7	14.1
Pinus resinosa	8.3	3.0	8.0	4.6	8.1	3.8	12.0	9.2
Pinus strobus	56.4	27.8	49.4	36.4	25.4	13.0	24.7	13.4
Populus spp.	15.2	4.9	11.5	4.3	19.4	6.3	24.0	9.6
n =	1058		696		992		600	
$\bar{X}$ dbh (in.)	11.2		12.7		10.2		10.0	
$\bar{X}$ point-to-tree distance (ft.)	n.d.		7.7		n.d.		6.8.	
$\bar{X}$ density (trees/acre)	n.d.		67.9		n.d.		86.9	

Species Distribution: Computer plotted maps of species distribution provided additional information about the early vegetation. The distribution of the birches (Figure 1) reflects the nomenclatural problem discussed earlier and is a surveying artifact. Other maps indicate that species distribution is more or less random, i.e. no clear patterns are discernable. One exception to this is the map for the ashes (Fraxinus sp.). This taxon appears to be distributed along stream courses, but the smaller number of individuals reported is limiting. The maps for white pine and tamarack (Figure 2), however, show them to occupy separate areas of the basin. The line of separation is somewhat parallel to the 1100 foot contour line which is an approximation of the old glacial Lake Duluth bed. This boundary tends to separate sandy, poorly drained soils outside of the former lake bed from the clayey, better drained soils of lacustrine origin. No other discernable patterns relating tree species to soil, slope or other characteristics of the basin were noted.

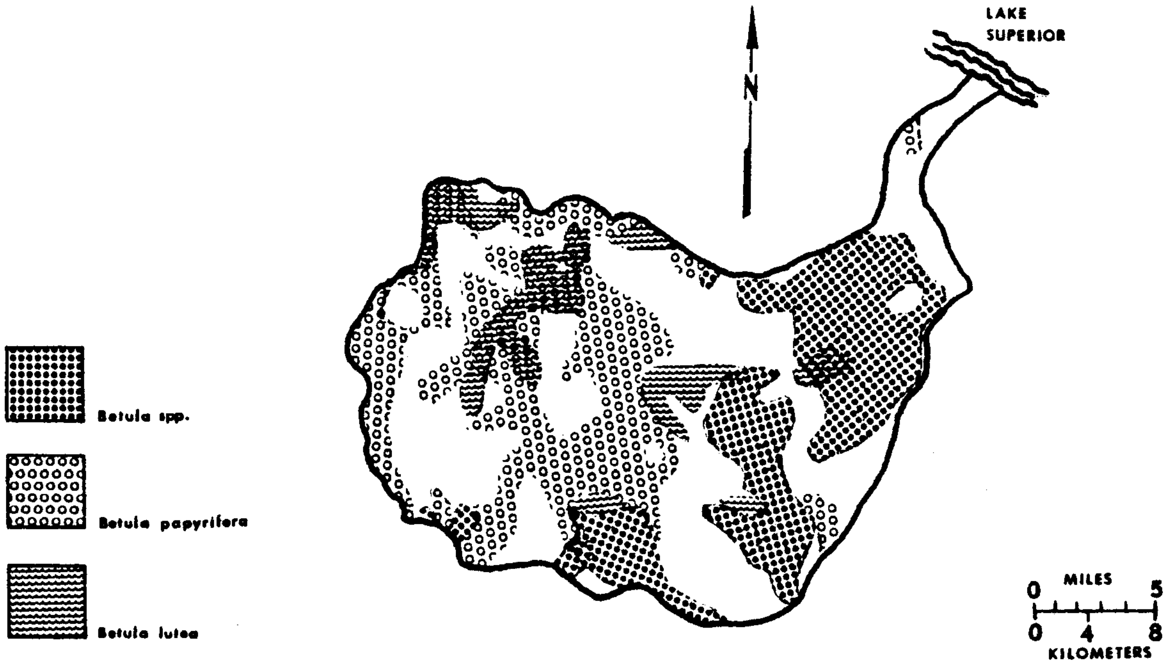


Figure 1. Species distribution map for birch (<u>Betula</u> spp.) in the Nemadji River Basin prepared from surveying records.

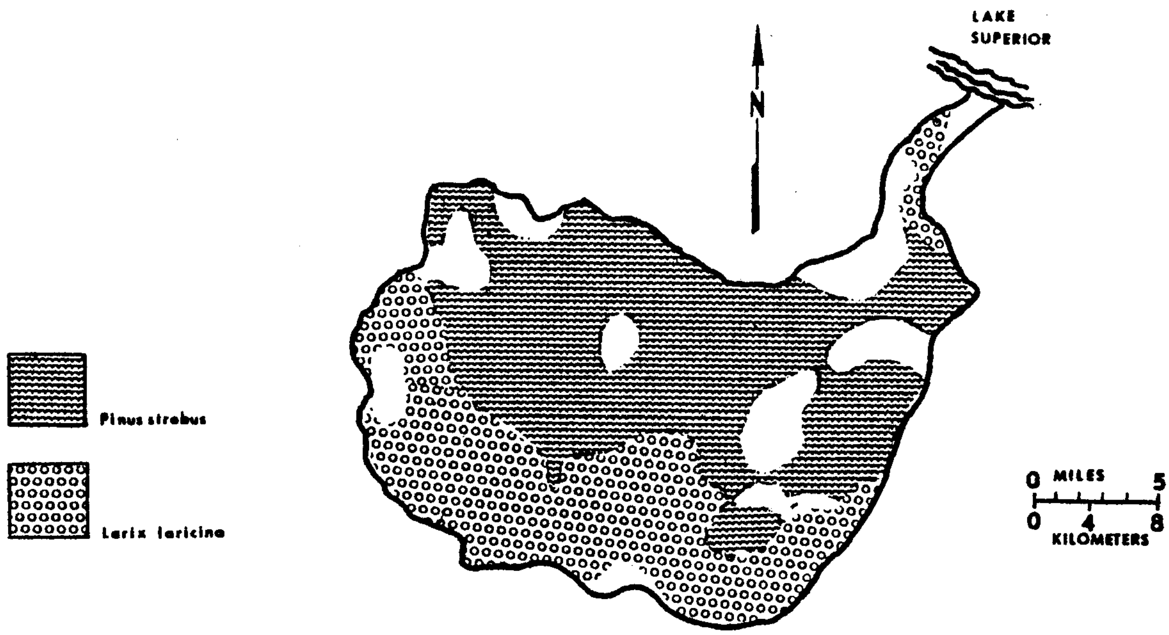


Figure 2. Species distribution map for tamarack and white pine in the Nemadji River Basin prepared for surveying records.

Size Class Profiles: When the size class frequency distributions of various species are tabulated, some interesting comparisons are possible. Probably most interesting are those of white pine (Figure 3). This tree, the major dominant in the basin, is represented with individuals in every size class, but tends to have many individuals 24 inches or larger DBH. A smaller number of smaller sized trees suggest some reproduction is occurring in the basin and all sub-parts examined with the exception of the corners located in the ravines. Here there is evidence of no reproduction. Further, the species composition in the ravines suggest a pattern characteristic of greater forest maturity than the comparative upland corners. White pine comprises 30.7% of the species reported in the ravines as compared with 13.9% in the uplands. Two species groups generally associated with younger forests, birch (*Betula* spp.) and poplar (*Populus* spp.), show the reverse trend, though not as dramatically. Thus, birch comprises 14.6% of the trees in the ravine compared with 18.8% in upland forests. Comparable figures for poplar are 4.1% and 6.7% respectively.

Ordination: The distribution of *Pinus strobus* and *Larix laricina* suggest that the boundary of the glacial Lake Duluth was a major demarkation of forest types. However, the ordination did not support this interpretation. the percentage of wetlands of each township appears to be correlated with community (township) position on the ordination as determined by percentage similarity. Upon inspection of Figures 4 and 5, one can see that *P. strobus* and *L. laricina* dominate opposite extremes.

II. CONTEMPORARY VEGETATIONAL COVER

Procedures

Based upon a review of the aerial photography of the basins, it was possible to determine, prior to the field season, major vegetative stands. Throughout the summer, collections were made in an effort to enumerate the species present in the basin, but the major work effort was directed toward quantifying the species composition of the previously identified stands, revising the delimitation of these stands and noting their extent for an accurate map of their coverage.

Trees: Sampling trees was done following point-centered quadrat procedures. Twenty-five points along north bearing transects were sampled at each location. The location of the transects was determined by using a transparent plastic grid which was placed over the basin map. By referring to a table of random numbers, locations on the grid were determined and that location was selected as the initial point of the transect. In the field, the actual site

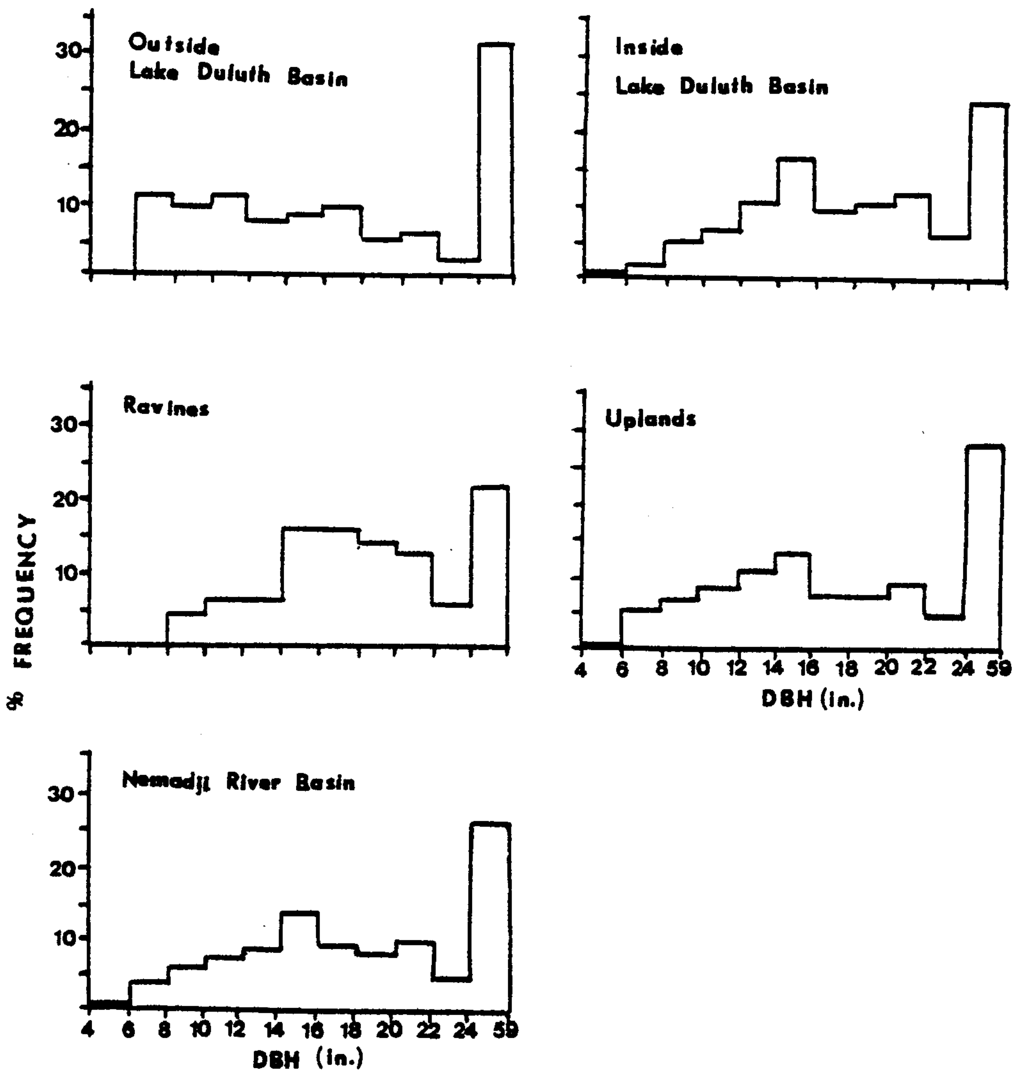
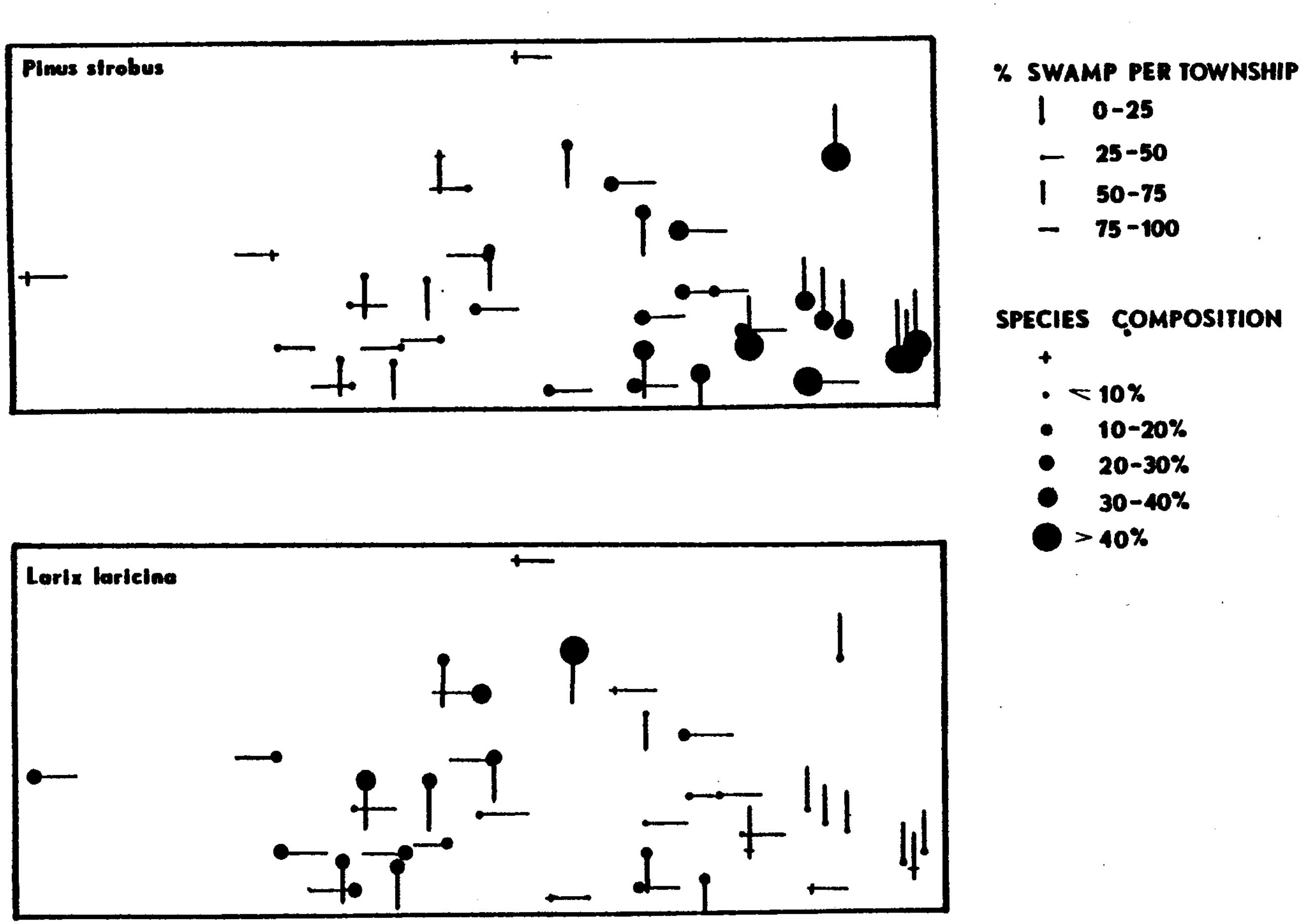


Figure 3. Size Class Distribution of *Pinus Strobus*.



Figures 4-5. Ordination of Nemadji River Basin forest communities (townships) showing community position and percentage of white pine (*Pinus strobus*), Figure 4; and tamarack (*Larix laricina*), Figure 5.

of each transect was made by throwing a stone over the shoulder and starting the transect at the site of impact. A compass was used to identify the transect line which was projected north from the initial point. Additional points were taken every 75 meters (by pacing) along the transect. If the vegetational boundary was reached before completing 25 points, an additional transect was determined.

Shrubs: A 100 square meter area was selected for sampling at every five points along the transect line at the time the tree data was being gathered. Stems of each species of shrub in the sample area were counted and recorded.

Because this procedure provided only frequency and density data for shrubs, it was later modified for use in comparing vegetation between slumped and non-slumped sites. Shrubs were classified in the field into six size classes, as modified from Loucks and Schnur (7). The size classes used were:

1) $<$15 cm tall
2) $>$15 cm high and $<$0.5 cm dia. at 15 cm
3) 0.5-1.0 cm dia. at 15 cm
4) 1.0 cm dia. at 15 cm to 1.0 cm at breast height (1.37 m)
5) 1.1-2.9 cm at breast height
6) 3.0-9.9 cm at breast height

Herbs: Sampling of the herbaceous cover was made by clipping all the non-woody plants at ground level from a 0.25 m^2 circular quadrat in the stands sampled. The general location of each quadrat was determined by the same procedure used to determine the initial point of the transect. Once in the field at the general location of the sampling point, the specific quadrat location was determined by throwing the hoop over the left shoulder. The plants were sampled within the hoop where it landed. Generally, the plants were sorted to species in the field and placed in paper bags. Upon returning to the laboratory, they were air dried and stored until they could be oven-dried to constant weight and their weights determined. The biomass thus determined for the herbaceous plants was used as the basis for defining major constituents of the herbaceous cover in the study area.

Analysis

Trees: In all cases, analysis of the data was done by computer and follows standard procedures as outlined by Grieg-Smith (3). For the trees, the procedure used to examine the presettlement composition of the basin was used to summarize the major tree species present. The density, dominance and frequency of each species, and the relative density, relative dominance and relative frequency for each was calculated. In addition, the number of trees per unit area, average diameter and the mean point-to-tree distance for each defined woody stand was determined.

Shrubs: Shrub data was also summarized to give density and frequency as well as the relative density, relative frequency and importance value.

Herbs: Herbaceous cover was summarized using the same procedures as for the previous data except that dominance was based upon phytomass (in grams) of the species present. Density values are not available with this data. In addition, sampling of the herbaceous cover was done three times (spring, summer and fall) during the growing season in order to obtain information about the seasonal changes in species composition.

Community Typification

The relative extent of each community type as identified in aerial imagery and substantiated in the field in the two basins is presented in Table 5. Areas are determined from planimetric measurements from the completed map and represent a rough index of the importance (in area covered) of each community type.

An enumeration of the species present in the study areas is presented in Appendix I.

Brief descriptions of the communities and their major constituent species are presented in Appendix II.

Tables 1-6 in Appendix III summarize the major (as determined by Importance Value) tree species within the Little Balsam communities sampled. Tables 7-12 present similar data for shrubs. Tables 1-6 in Appendix IV summarize the woody vegetation in the Skunk Creek communities sampled. Since the community composition differs between the study basins, it was not feasible to obtain equivalent samples of each community type, particularly for woody vegetation.

Tables 1-11 in Appendix V summarize the major herbaceous species, by season, (as determined by Importance Value) found in the two study basins. Sampling periods were in late May to early June (vernal), mid July (aestival) and late September (autumnal). The stands reported represent cover types that constitute some 85% of the basins (see Table 5) and were those stands where a minimum of five quadrats were sampled over the season. Over 200 species were reported from the quadrat samples but less than 10% of these constituted over 75% of the total phytomass.

Table 5. Major Vegetation Types and Area, Little Balsam and Skunk Creek Basins.

	Little Balsam		Skunk Creek	
	Area (Acres)	% of Total	Area (Acres)	% of Total
Woodlands				
I. Aspen Hardwoods	418	13.3	201	3.0
II. Northern Hardwoods				
A. Aspen/Birch Dominant	962	30.5	2999	45.2
B. Oak/Maple Dominant	409	13.0	288	4.3
C. Maple/Basswood Dominant	147	4.7	73	1.1
III. Conifer	70	2.2	138	2.1
IV. Ravine Forest	182	5.8	213	4.7
V. Plantations	28	0.9	43	.6
Wetlands				
VI. Hardwood Swamp	378	12.0	600	9.0
VII. Conifer Swamp	21	0.6	231	3.5
VIII. Bog	64	2.0	10	.2
IX. Marsh				
A. Wet Shrubland	102	3.2	206	3.1
B. Marsh			7	.1
Fields				
X. Abandoned				
A. Herbaceous	2	0.1	41	.6
B. Shrubby	29	0.9	28	.4
XI. Agricultural Fields	542	10.8	1455	21.9
XII. Construction Zone			7	0.1

The mean phytomass (g/m^2) for each community type identified and sampled is given in Table 6 below. Highest values are found in the open areas, with one exception.

Table 6. Average Phytomass (g/m^2) of Herbaceous Cover by Stand (n)= number quadrats

	Little Balsam		Skunk Creek	
Aspen	(20)	50.1	(6)	47.6
Aspen-Birch	(17)	51.6	(34)	47.6
Oak-Maple	(18)	23.6	(4)	43.7
Maple-Basswood	(2)	14.3	(3)	27.6
Coniferous[a]	(5)	36.6	(3)	87.3
Ravine Forests	(18)	68.5	(15)	43.3
Plantations			(3)	155.6[c]
Wetland-Forest	(7)	304.8[b]	(18)	63.4
Field-Shrubby	(9)	141.3	(6)	108.8
Field-Herbaceous	(4)	120.6		
Agricultural	(4)	120.6	(20)	117

[a]These stands were very dissimilar between basins as indicated by the I.S. (see Table 7).

[b]Includes unusually high Equisetum samples.

[c]Young pine plantation and very open.

Maps which illustrate the location of the major community types in each basin were prepared using available aerial photography. Field reconnaisance was used to verify the accuracy of the maps, and changes were made where necessary. These maps are attached in Appendix VI.

Vegetation of slumped and non-slumped sites was examined by use of previously defined sampling procedures. Table 7 summarizes the results of vegetative sampling. Only those species with Importance Percentage (I.P.) values exceeding five are included.

Discussion

Community Composition: A comparison of the composition of the plant communities between the two basins reveals that vegetation is not very similar (Table 6). The index of similarity between the basins for each stand was determined as:

$$I.S. = \frac{w}{a+b}$$

where w = smallest phytomass value of each species occurring in both basins, and
a+b = sum of phytomass in each basin.

The aspen and wetland hardwood stands which are characterized by unequal samples show the lowest I.S. values, probably a result of sampling. The other stands have low

Table 7. Comparison of Major (I.P. Values > 5.0) Species Vegetation on Slump Sites and Non-Slump Sites, Nemadji River Basin. (n = quadrat number)

Taxa	SLUMP (n = 21)				NON - Slump (n = 18)			
	Relative Dominance	Relative Density	Relative Frequency	Importance Frequency	Relative Dominance	Relative Density	Relative Frequency	Importance Percentage
TREES	Density = 248 trees/hectare				Density = 606 trees/hectare			
Populus tremuloides	46.2	42.3	50.0	46.2	44.4	44.9	36.7	42.0
Abies balsamea	43.0	44.2	31.8	39.7	30.0	37.6	23.3	30.3
Picea glauca	6.2	7.7	9.1	7.6				
Betula papyrifera	4.6	5.8	9.1	6.5	22.3	12.8	23.3	19.5
SHRUBS								
Populus tremuloides	21.9	5.6	7.6	11.7	19.9	3.8	8.2	10.6
Abies balsamea	11.6	10.3	4.7	8.8	11.6	7.2	5.1	8.0
Diervilla lonicera	6.2	14.5	5.4	8.7				
Corylus cornuta	7.2	8.6	6.5	7.5	18.6	19.8	7.2	15.2
Rosa sp.	4.6	9.6	6.5	6.9	4.5	11.0	6.7	7.4
Salix sp.	5.5	4.7	5.8	5.3				
Cornus rugosa	6.5	5.2	4.0	5.2				
C. stolonifera	5.1	5.0	5.1	5.1	13.5	17.6	7.2	12.7
Fraxinus sp.					4.2	8.1	4.1	5.5
Viburnum rafinesquianum					3.7	6.5	5.1	5.1
HERBS								
Fragaria virginiana	11.6	N.A.	6.5	9.0				
Equisetum arvense	9.5	N.A.	6.1	7.8				
Carex sp.	7.4	N.A.	4.3	5.9	5.2	N.A.	5.6	5.4
Lathyrus venosus	7.4	N.A.	3.5	5.4				
Aster macrophyllus	6.1	N.A.	4.4	5.2	34.0	N.A.	8.9	21.5
Sanicula marilandica					8.4	N.A.	4.5	6.4
Cornus canadensis					6.1	N.A.	4.5	5.3

I.S. values which suggests that vegetation in both basins is dissimilar. (An I.S. of .85 is an arbitrary value reflecting sampling error for considering stands to be similar.) The low I.S. values are consistent with the differing land use practices observed between the basins.

An examination of species diversity for the stands reported in the Appendix revealed relatively low indices in all instances, perhaps in part the result of small sample sizes. Two diversity indices were determined for these stands (Table 8). These were Simpson's Index of Diversity:

$$C = \sum_{i=1}^{n} \left(\frac{Ni}{N}\right)^2$$

and the Shannon-Wiener Diversity Index:

$$H = \sum_{i=1}^{n} \left(\frac{Ni}{N}\right) \log \left(\frac{Ni}{N}\right)$$

where $\frac{Ni}{N}$ is the decimal importance percentage for each species.

Table 8. Comparison of Diversity and Similarity for Stands.

Stand	Shannon-Wiener	Simpson	Index of Similarity
Aspen	1.454/1.197	.071/.098	0.21
Aspen-Birch	1.551/1.556	.051/.058	0.53
Ravine Forest	1.232/1.333	.107/.098	0.44
Wetland Hardwoods	1.055/1.579	.218/.041	0.26
Agricultural Fields	1.605/1.613	.032/.037	0.59

Two stands (aspen and wetland hardwoods) show dissimilar diversity indices between basins, but this is probably a reflection of dissimilar sample sizes.

Forest Communities: If the forested stands are arranged according to a likely successional pattern from aspen to the maple-basswood unit, it is possible to examine the relationships between each component of the vegetation. Because of the site characteristics of the wetland hardwoods and the coniferous stand of the Skunk Creek Basin (both poorly drained), they are omitted from further analysis since it is assumed they are not representative of upland successional stages. The vegetation of the ravine forest is distinctly a bottomland forest type (with high concentrations of elm and ash) and also is omitted from comparisons since they likely represent a response to a specific environment and do not fit into the upland successional sequence.

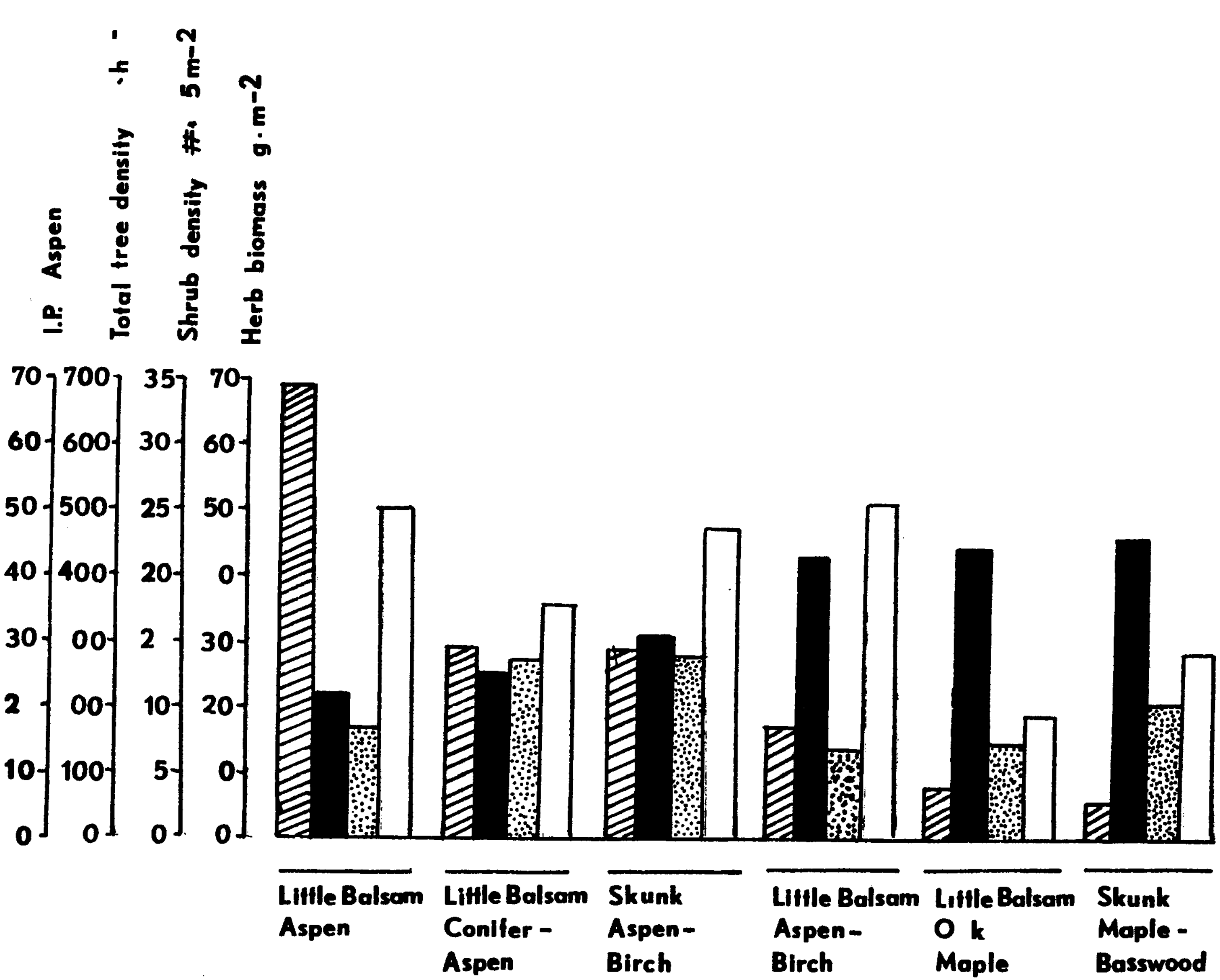


Figure 6. Community structure of successional stands ranked in order of decreasing Importance Percentage (IP) of aspen (*Populus tremuloides*).

Figure 6 illustrates the relative values of aspen importance, tree density ($\#/ha^2$), shrub density ($\#/25\ m^2$) and herb phytomass (g/m^2) between these stands.

Correlations of various components of the vegetation were sought. A significant correlation of potential importance to the erosion problem is the inverse relationship between aspen I.P. and total stand density ($trees \cdot ha^2$) ($r=-0.87$, significant at 0.01 level). Linear regression analysis of shrub density and herb biomass reveals no trend ($r=0.01$). The correlation of tree density and shrub density was not significant ($r=0.46$), nor is there any demonstrable relationship between shrubs and aspen importance ($r=0.03$). The aspen tend to be more open than other types, having $\sim$200 $trees \cdot ha^2$ compared to 450 $trees \cdot ha^2$ in the maple basswood. Since the diameters of all communities was similar ($\bar{X}=19.7 \pm 1.47$ cm) the aspen stands also had the smallest phytomass. No significance was found between tree density and herb phytomass ($r=0.50$). Likewise there is a positive, but not significant trend between density and aspen importance percentage ($r=0.64$). If shrub density and herb phytomass are relativised (expressed as a percentage of the maximum value) and combined, there is a moderate inverse trend, but no significant correlation ($r=-0.69$) between tree density and the shrub-herb component.

Documentation of these trends would require additional datapoints, not currently available. The data suggests, however, that the increase in biomass of the herbs to be expected under a more open canopy in the less dense stands of aspen may be less than anticipated. Additional work to clarify the potential relationships between aspen and ground cover may be warranted.

Comparisons of presettlement tree vegetation and current vegetation reveals significantly different stand composition. It should be noted that ravine forests, both then and now, are characterized by trees somewhat larger than upland forests. Since the composition of the presettlement and current ravine forests are so dissimilar, however, this comparison may be insignificant though it suggests ravines provide a better environment for growth for trees than upland sites even though disturbance from slumping may be adverse to growth. However, present vegetation between ravines and upland sites is not similar which contrasts with the situation apparently present with presettlement vegetation. The composition of the forests, as extracted from the surveying records revealed forests in which trees differed in size between ravine and upland sites, but not in species composition or the relative significance between species.

<u>Slump-non-slump vegetation</u>. Based on the I.P. values reported in Table 7, white birch (*Betula papyrifera*) and hazel (*Corylus cornuta*) are more important in the vegetative

cover of non-slump (stable) areas. Interestingly, birch has a higher modulus of rupture (an indirect measure of root tensile strength) value (44,000 Kp) (see plant root tensile strength discussion) than aspen, fir or spruce (ca. 35,000 Kp). A comparison of the tensile strength of shrub roots reveals that hazel has much stronger root strength than other shrub species tested. The occurrence of these stronger rooted species in greater abundance on non-slumped sites suggests that they may have an important role in slope stability. However, this conclusion must be accepted with caution because slump vegetation is on disturbed sites which are more open, a factor which may be a major factor in determining the cover. Many of the species with stronger root strength tend to be shade tolerant so their establishment on slump sites is slower. Aspen forests and fields constitute the major vegetation types on clay soils in the basins. Both provide good ground cover though forest stands contribute less sediment than herbaceous cover types. The effect of plant roots and transpiration to soil stability, reported elsewhere, suggests that not all cover types are equally suited to reducing red clay erosion.

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APPENDIX I

FLORA OF THE SKUNK CREEK BASIN, CARLTON COUNTY, MINNESOTA AND OF THE LITTLE BALSAM BASIN, DOUGLAS COUNTY, WISCONSIN

Nomenclature of the dicots follows Gleason and Cronquist (1) except for the monocots which follows Voss (2). In a few instances more recent nomenclatural changes have been used. The order of families follows the familiar Engler-Prantl sequence but within families and genera taxa are listed alphabetically. The basin in which each taxon occurs is indicated with a B (for Little Balsam) or S (for Skunk Creek). An asterisk (*) denotes sight record only.

SPECIES	LOCATION	HABITAT
Lycopodiaceae		
Lycopodium annotinum L.	B	conifer swamp
L. clavatum L.	B, S	moist woods, conifer woods
L. complanatum L. var. *flabelliforme* Fern.	B, S*	moist woods
L. lucidulum Michx.	B, S	creek bank, shady moist woods
L. obscurum L. var. *dendroideum* (Michx.) DC. Eat.	B, S	shady mature hardwoods
Equisetaceae		
Equisetum arvense L.	B, S	roadside bank, ditch, sand, gravel, clay
E. fluviatile L.	B, S	shallow water, ditch, creek bank
E. hymale L.	B, S	open disturbed areas, sand, clay
E. palustre L.	B	sandy creek bank
E. pratense Ehrh.	B, S	open to shady moist woods
E. scirpoides Michx.	B, S	steep creek bank, shady moist conifer woods
E. sylvaticum L.	B, S	moist woods
Ophioglossaceae		
Botrychium matrecariae-folium A. Br.	S	shady, moist deciduous woods (uncommon)
B. virginianum (L.) Sw.	B, S	shady, moist deciduous woods (uncommon)
Botrychium sp.	S	sunny open woods, sand (uncommon)

SPECIES	LOCATION	HABITAT
Osmundaceae		
Osmunda cinnamomea L.	B*, S	shady ash swamp, creek bank, peat
O. claytoniana L.	B, S	rich hardwoods, swamp woods
O. regalis L.	B	dense shade, ash/fir swamp (uncommon)
Polypodiaceae		
Athyrium filix-femina (L.) Roth. var. *michauxii* (Spreng.) Farwell.	B, S	ditch, wet meadow, moist woods, swamp
Dryopteris cristata (L.) A. Gray	B, S	wet ditch, creek bank, wet shady woods, bog
D. spinulosa (O.F. Mull.) Wat. var. *americana* (Frisch.) Fern.	S	shady woods
D. spinulosa (O.F. Mull.) Wat. var. *spinulosa*	B, S	wet ditch, creek bank, wet woods, bog, ash swamp
Gymnocarpium dryopteris (L.) Newm.	B, S	creek bank, moist shady woods, swamp
Matteuccia struthiopteris (L.) Todaro.	B, S	shady moist woods, swamps
Onoclea sensibilis L.	B, S*	wet ditch, edge of swamp woods
Pteridium aquilinum (L.) Kuhn.	B*, S	roadside, old field, dry open woods
Thelypteris phegopteris (L.) Slosson	B	creek bank, wet woods, swamp
Pinaceae		
Abies balsamea (L.) Mill.	B*, S	moist woods, swamp
Larix laricina (DuRoi) K. Koch	B	bog
Picea abies Karst.?	B	maple woods, introduced (uncommon)
P. glauca (Moench.) Voss.	B, S	rich moist woods
Pinus banksiana Lamb.	B*, S	dry woods, sand
P. mariana (Mill.) BSP.	B*, S*	moist woods, conifer swamp, bog
P. resinosa Ait.	B*, S	dry woods, sand
P. strobus L.	B*, S*	woods, sand
Thuja occidentalis L.	B, S	wet woods, conifer swamp
Typhaceae		
Typha latifolia L.	B, S	wet ditch, marsh

SPECIES	LOCATION	HABITAT
Sparganiaceae		
Sparganium chlorocarpum Rydb.	B, S	creek bottom, bog, peat (uncommon)
Najadaceae		
Potamogeton sp.	S	pond of drainage water, sand bottom (uncommon)
Alismataceae		
Alisma plantago-aquatica L.	B	woodland pool
Sagittaria cuneata Sheldon?	B	creek bottom
S. latifolia Willd.	S	bog shore, peat
Gramineae		
Agropyron repens (L.) Beauv.	B, S	roadside, sand, gravel
Agrostis gigantea Roth.	B, S	wet ditch, old field, wet meadow, bog/ field edge
Andropogon gerardi Vitm.	B, S	roadside, dry sand and gravel
Avena fatua L.	B	railroad ballast
A. sativa L.	S	cultivated in field, cracks in pavement
Beckmannia syzigachne (Steudel.) Fern.	S	wet roadside ditch, clay (uncommon)
Brachyelytrum erectum (Schreb.) Beauv.	B, S	wet ditch, moist, open woods
Bromus ciliatus L.	B, S	wet ditch, mesic woods
B. inermis Leyss.	B, S	roadside, railroad tracks, old field
B. kalmii Gray	B, S	mowed field, dry woods, sand, woods/ field edge
Calamogrostis canadensis (Michx.) Beauv.	B, S	wet ditch, bog
Cinna latifolia (Trev.) Griseb.	B, S	moist woods
Danthonia spicata (L.) Beauv.	B, S	dry woods, sand
Digitaria ischaemum (Schreb.) Muhl.	B	dry roadside, sand
Echinochloa crusgalli (L.) Beauv.	B	road, sand
E. muricata (Beauv.) Fern.	B	road, sand
Elymus canadensis L.	S	roadside, wet ditch
E. virginicus L.	S	roadside, railroad tracks, creek bank, clay, sand

SPECIES	LOCATION	HABITAT
Eragrostis pectinacea (Michx.) Nees.	B	dry roadside, sand
Festuca obtusa Biehler	S	hardwood swamp
F. ovina L.	B, S	roadside, old field (uncommon)
F. saximontana Rydb.	S	roadside, gravel (uncommon)
Glyceria canadensis (Michx.) Trin.	S	bog edge, peat
G. grandis S. Watson	B	wet ditch, sand
Glyceria striata (Lam.) Hitchc.	B, S	creek bank, alder swamp, wet woods
Hordeum jubatum L.	B, S	roadside ditch, old field
Hystrix patula Moench	B, S	shady creek bank
Leersia oryzoides (L.) Sw.	B	roadside ditch
Leptoloma cognatum (Schult.) Chase	B	railroad ballast
Milium effusus L.	S	railroad tracks (uncommon)
Muhlenbergia frondosa (Poir.) Fern.	B, S	old field, creek bottoms
M. glomerata (Willd.) Trin.?	S	creek bottoms
Oryzopsis asperifolia Michx.	B, S	creek bank, moist woods
Panicum capillare L.	B	old field
P. lanuginosum Ell.	S	roadside
P. miliaceum L.	S	railroad tracks (uncommon)
P. praecocium Hitchc. and Chase	B, S	roadside
Phalaris arundinacea L.	B, S	roadside, old field, creek bank, clay
Pheum pratense L.	B, S	roadside, old field, sand, clay
Poa annua L.	S	creek bottoms
P. compressa L.	B, S	old field
P. nemoralis L.	B, S	roadside, railroad tracks, old field, old woods
P. palustris L.	B, S	wet meadow
Luzula acuminata Raf.	B, S	open woods, creek floodplain, clay
Liliaceae		
Allium tricoccum Ait.	B	shady wet woods, swamp
Asparagus officinalis L.	B	old farm yard, sand
Clintonia borealis (Ait.) Raf.	B, S	rich woods, creek banks

SPECIES	LOCATION	HABITAT
Hemerocallis fulva L.	B, S	roadside, old farm-yard, excape
Lilium superbum L.	B, S	wet ditch, edge of popple woods
Maianthemum canadense Desf.	B, S	rich woods, fir forest, river bottoms
Smilacina racemosa (L.) Desf.	B, S	rich, moist woods
S. stellata (L.) Desf.	B, S	creek bottoms
S. trifolia (L.) Desf.	B	bog, conifer swamp, fir forest
Smilax herbacea L. var. *lasioneuron* (Small.) Rydb.	S	shady creek bank
Polygonatum pubescens (Willd.) Pursh	S	shady moist woods
Streptopus amplexifolius (L.) DC.	B, S	rich woods
S. roseus Michx.	B, S	rich, moist woods
Trillium cernuum L. var. *macranthum* Eames and Wieg.	B, S	rich woods, creek bottoms
T. grandiflorum (Michx.) Salisb	S	moderately open woods
Uvularia grandiflora Sm.	B, S	shady woods, clay
U. sessilifolia L.	B, S	sunny to shady woods
Iridaceae		
Iris versicolor L.	B	sparse shade, alder swamp
I. virginica L. var. *shrevei* (Small.) Anders.	B, S	wet ditch, bog shore, creek bank, clay
Sisyrinchium montanum Greene	B, S	wet meadow, open bank, clay
P. pratensis L.	B, S	old field
Puccinellia pallida (Torr.) Clausen?		bog edge, peat (uncommon)
Setaria glauca (L.) Beauv.	B	roadside, clay, sand, gravel
S. italica (L.) Beauv.	B	railroad ballast
Spartina pectinata Link.	B	moist roadside, sand
Triticum aestivum L.	B	railroad ballast, cultivar
Cyperaceae		
Carex aurea Nutt.	S	sandy soil, wet ditch
C. intumescens Rudge	B	woods
C. pensylvanica Lam.	B, S	railroad tracks, open woods
C. retrorsa Schw.	B	swampy area along creek

SPECIES	LOCATION	HABITAT
Carex spp.	B, S	being determined
Cyperus schweinitzii Torr.?	B	wet ditch
Eleocharis obtusa (Willd.) Schultes	B, S	bog, sandy floodplain
Eriophorum spissum Fern.	B	bog margin
Eriophorum sp.	B, S	bog, dry creek bed, sand
Scirpus atrovirens Willd.	B, S	wet meadow, wet ditch
S. cyperinus (L.) Kunth.	B, S	wet meadow, wet ditch
Araceae		
Arisaema atrorubens (Ait.) Blume	B, S	floodplain, rich woods, clay creek bank
Lemnaceae		
Lemna minor L.	B, S	wet ditch along railroad tracks
Juncaceae		
Juncus bufonius L.?	B	sandy roadside
J. effusus L.	B, S	wet ditch, sandy shore of pond, clay bank
J. greenei Oakes and Tuck.	B	wet ditch
J. tenuis Willd.	B, S	wet meadow, roadside ditch
Fagaceae		
Quercus borealis Michx.	B, S	mixed woods, sand
Q. macrocarpa Michx.	B, S	mixed hardwoods, sand and clay
Ulmaceae		
Ulmus americana L.	B, S	hardwood swamp
Moraceae		
Humulus lupulus L.	S	creek bottoms (uncommon)
Urticaceae		
Laportea canadensis (L.) Wedd.	B, S	creek bank, moist shady woods
Pilea pumila (L.) Gray.	S	creek bank, wet woods
Santalaceae		
Comandra umbellata (L.) Nutt.	B, S	dry sand and gravel, railroad tracks

SPECIES	LOCATION	HABITAT
Aristolochiaceae		
Asarum canadense L.	B, S	creek bottoms, hard-wood swamp
Polygonaceae		
Polygonum achoreum Blake	B	roadside gravel
P. aviculare L.	S	roadside, gravel, clay
P. cilinode Michx.	B, S	old field, woods path, roadside, sand
P. coccineum Muhl.	S	dry creek
P. convolvulus L.	S	dry creek, roadside, gravel
P. erectum L.	B	roadside
P. hydropiper L.	S	moist disturbed area, sand
P. lapathifolium L.	B, S	roadside, ditch, sand
P. pensylvanicum L.	B	sandy road, disturbed
Orchidaceae		
Corallorhiza maculata Raf.		shady woods
C. trifida Chat.	B, S	shady woods, creek bottoms
Cypripedium acaule Ait.	B	conifer swamp, ash/fir woods (uncommon)
C. calceolus L.	B	rich, shady woods (uncommon)
C. reginae Walt.	S	creek bank, clay (uncommon)
Habenaria clavellata (Michx.) Spreng.?	B	bog on sphagnum hummock
H. hyperborea (L.) R. Br.	B, S	hardwood swamp, wet woods, wet meadows
H. psycodes (L.) Spreng.	B, S	wet open woods, road-side ditch, clay
Salicaceae		
Populus balsamifera L.	B, S	creek bank, wet woods, clay
P. gradidentata Michx.	B, S	dry to moist woods, clay
P. tremuloides Michx.	B, S	open woods, clay
Salix bebbiana Sarg.	B	hedgerow, young woods, creek bank
S. discolor Muhl.	B	open woods, road bank
S. interior Rowlee	B	open area long creek
S. pedicellaris Pursh.	S	bog edge
S. petiolaris Sm.	B	open area near creek

SPECIES	LOCATION	HABITAT
Betulaceae		
Alnus rugosa (DuRoi) Spreng.	B, S	wet ditch, creek bank, swamps
Betula alleghaniensis Britt.	B	creek bottoms, rich woods (uncommon)
B. papyrifera Marsh.	B, S*	dry to moist woods
Corylus americana Walt.	B, S	dry to moist woods, creek bank, clay
C. cornuta Marsh.	B, S	moist woods, wet ditch, creek bank
Ostrya virginana (Mill.) K. Koch	B	low wet woods, clay
P. persicaria L.	S	ditch, roadside, sand
P. sagittatum L.	B, S	wet ditch
P. scandens L.?	B	roadside, clay
Rumex acetosella L.	B, S	roadside, railroad tracks, creek bank, clay and sand
R. crispus L.	B, S	roadside, ditch, clay and sand
R. obtusifolius L.		shady creek bottoms, sand
R. patientia L.	S	wet ditch
Chenopodiaceae		
Chenopodium album L.	B, S	roadside, sand and gravel
Salsola kali L.	S	roadside, gravel
Amaranthaceae		
Amaranthus retroflexus L.	S	railroad tracks, roadside, sand and gravel
Nyctaginaceae		
Mirabilis nyctagineus (Michx.) MacM.	B, S	open field, railroad tracks, sand and gravel
Aizoaceae		
Mollugo verticillata L.	B, S*	sandy road, railroad ballast
Portulacaceae		
Portulaca oleracea L.	B, S	sandy road, garden
Caryophyllaceae		
Arenaria lateriflora L.	B, S	shady mesic woods
Cerastium fontanum Baumg.	B, S	weedy clearing, woods path
Lychnis alba Mill.	B, S	old field, railroad tracks, roadside, ditch

SPECIES	LOCATION	HABITAT
Saponaria officinalis L.	B, S	railroad tracks, roadside ditch, sand
Silene antirrhina L.	B	railroad ballast (uncommon)
S. cucubalus Wibel.	B, S	railroad tracks, sand and gravel
Stellaria calycantha (Ledeb.) Bong.	B	shady wet woods
S. longifolia Muhl.	B, S	roadside ditch, bog, hardwood swamp
Nymphaceae		
Nuphar advena Ait.	S	bog, in 4 inches water, peat
Ranunculaceae		
Actaea pachypoda Ell.	B, S	shady hardwood swamp, creek
A. rubra (Ait.) Willd.	B, S	creek bank, creek bottomland, hardwood swamp
Anemone canadensis L.	B, S	wet ditch, roadside
A. cylindrica Gray	B, S	roadside ditch, woods/field edge, clay
A. quinquefolia L.	B, S	mixed hardwoods, roadside
A. riparia Fern	B, S	open woods, wet ditch, roadside, wet woods, sand
A. canadensis L.	B, S	open woods, creek bank, roadside
Caltha palustris L.	B, S	wet ditch, swamp
Clematis virginiana L.	S	creek bank, roadside, clay
Coptis trifolia (L.) Salisb.	B, S	shady hardwood swamp
Hepatica americana (DC.) Ker.	B, S	open woods, clay
Ranunculus abortivus L. var. *acrolasius* Fern.	B, S	shady hardwood swamp, moist woods
R. acris L.	B, S	wet meadow, roadside ditch, hardwood swamp, creek bottoms
R. pensylvanicus L.	S	wet ditch
R. recurvatus Poir.	B, S	alder swamp, wet ditch, shady hardwood swamp
R. septentrionalis Poir.	B, S	creek bank, dry creek bed

SPECIES	LOCATION	HABITAT
Thalictrum dasycarpum Fisch and Avé-Lall.	B, S	ditch, roadside, shady creek bank
T. dioicum L.	B, S	open woods, shady creek bank
Berberidaceae		
Caulophyllum thalictroides (L.) Michx.	S	(uncommon)
Papaveraceae		
Sanguinaria canadensis L.	B, S	creek bank, shady woods, swamps
Fumariaceae		
Corydalis sempervirens (L.) Pers.	S	moist open woods, sand
Dicentra cucullaria (L.) Bernh.	B	creek bottoms (uncommon)
Crucifereae		
Barbarea vulgaris R. Br.	B, S	old field, creek bottoms, clay
Berteroa incana (L.) DC.	S	railroad tracks
Capsella bursa-pastoris (L.) Medic.	B	roadside edge, sand
Cardamine pensylvanica Muhl.	S	hardwood swamp
Erysimum cheiranthoides L.		roadside ditch
Lepidium densiflorum Schrad.	S	roadside ditch
Raphanus raphanistrum L.	S	weed in oat field, clay
Rorippa islandica (Oeder) Borbás var. *fernaldiana* Butt. and Abbé	S	wet ditch, wet meadow
Thlaspi arvense L.	B	dry gravel (uncommon)
Crassulaceae		
Penthorum sedoides L.	S	creek bank, gravel (uncommon)
Saxifragaceae		
Chrysosplenium americanum Schw.	B, S	swamp thicket
Mitella diphylla L.	B, S	shady moist woods (uncommon)
M. nuda L.	B, S	shady, moist woods, creek bank (uncommon)
Saxifraga pensylvanica L.	B, S	hardwood swamp, creek bottoms, shady wet meadow

SPECIES	LOCATION	HABITAT
Ribes americanum Mill.	B, S	shady hardwood swamp, creek bank
R. cynobasti L.	S	shady conifer woods, clay
R. glandulosum Grauer.	B, S	moist woods, swamps, creek banks, clay
R. hirtellum Michx.	B, S	moist woods, creek bank, swamp thicket
R. triste Pall.	B, S	creek bank, creek bottoms, shady hardwood swamp, clay
Rosaceae		
Amelanchier bartramiana (Tausch.) Roemer	B	woods clearing
A. laevis Wieg.	B	open mixed hardwoods
A. sanguinea (Pursh.) DC.	B	hedgerow
A. spicata (Lam.) K. Koch	B, S	open mixed hardwoods, creek bottoms, sand
Agrimonia striata Michx.	B, S	roadside, ditch
Crategus punctata Jacq.?	B	roadside clearing
Fragaria virginiana Duchesne	B, S	railroad track, bank, roadside bank, sand
Geum alleppicum Jacq.	B, S	old field, railroad tracks, clay
G. canadense Jacq.	S	shady hardwood swamp
G. laciniatum Murr.?	S	shady hardwood swamp
G. rivale L.	B, S	moist open woods, hardwood swamp
Potentilla argentea L.	S	roadside ditch, sand and gravel
P. norvegica L.	B, S	dry open woods, creek bank, sand and clay
P. palustris (L.) Scop.	S	open water, bog (uncommon)
P. recta L.	B	old field
P. simplex Michx.	B, S	edge of open woods, railroad tracks, sand
Prunus americana Marsh.	B	old farmyard
P. nigra Ait.	B, S	open woods, wet thicket creek bank
P. pensylvanica L.	B	roadside edge
P. virginiana L.	B, S	hedgerow, old field, shady creek bank, clay
Rosa acicularis Lindl. ssp. sayi (Schw.) Lewis	B, S	railroad tracks, road bank, clay, gravel
R. blanda Air.	B, S	roadside ditch, rail-road track, open hardwoods

SPECIES	LOCATION	HABITAT
Rubus allegheniensis Porter	B	old field, hedgerow
R. canadensis L.	B	cedar swamp
R. hispidus L.	S	railroad tracks
R. parviflorus Nutt.	B	rich moist woods, creek banks
R. pubescens Raf.	B, S	rich moist woods
R. strigosus Michx.	B	pasture, open woods
Spiraea alba DuRoi	S	swamp thicket
S. tomentosa L.	S	bog/field edge (uncommon)
Waldsteinia fragarioides (Michx.) Tratt.	B*, S*	dry to moist woods
Leguminosae		
Amphicarpa bracteata (L.) Fern.	B, S	dry creek, creek bank
Astragalus canadensis L.	B	old field, roadside edge (uncommon)
Caragana frutex Koch	B	road bank, cultivated (uncommon)
Lathyrus ochroleucus Hook.	B, S	roadside, woods/field edge
L. palustris L.	B	roadside edge, gravel
L. venosus Muhl. var. *intonsus* Butt. and St. John	B, S	roadside edge, railroad tracks, open woods, clay
Medicago sativa L.	B*, S	fields, railroad tracks
Melilotus alba Desr.	B, S	railroad ballast, roadside, sand and gravel
M. officinalis (L.) Lam.	B, S	railroad ballast, roadside, sand and gravel
Trifolium arvense L.	B, S	roadside, sand and gravel
T. aureum Poll.	S	roadside ditch
T. campestre Schreb.	B, S	roadside bank, ditch, clay
T. hybridum L.	B, S	railroad tracks, roadside edge, clay
T. pratense L.	B, S	railroad tracks, roadside, clay
T. repens L.	B, S	roadside, dry woods, sand and clay
Vicia americana Muhl.	B, S	open woods, roadside bank, ditch, clay
Geraniaceae		
Geranium bicknellii Britt.	S	roadside ditch, clay

SPECIES	LOCATION	HABITAT
Oxalidaceae		
Oxalis stricta L.	B, S	field edge, creek bank, roadside ditch, railroad tracks
Polygalaceae		
Polygala paucifolia Willd.	S	path in open woods (uncommon)
Euphorbiaceae		
Euphorbia maculata L.	B	railroad ballast
E. podperae Croiz.	S	railroad ballast (uncommon)
E. serpyllifolia Pers.	B, S	railroad ballast, cracks in pavement
Callitrichaceae		
Callitriche hermaphroditica L.	S	ruts in road (uncommon)
C. heterophylla Pursh.	B	rooted in shallow running water (uncommon)
Anacardiaceae		
Rhus typhina L.	B	railroad track bank, sand
Toxicodendron rydbergii (Small.) Rehder	B*, S	roadside edge, disturbed creek bank, open oak woods
Aquifoliaceae		
Ilex verticillata (L.) Gray	B, S	creek bank, swamp, marsh
Nemopanthus mucronatus (L.) Trel.	B, S	bog edge, conifer swamp, edge of boggy ditch
Celastraceae		
Celastrus scandens L.	S	creek bank, clay (uncommon)
Aceraceae		
Acer negundo L.	S	creek bank, clay
A. rebrum L.	B, S	mesic woods, clay and sand
A. saccharum Marsh.	B, S	rich, moist shady woods
A. spicatum Lamb.	B, S	alder swamp, rich shady woods, oak woods

SPECIES	LOCATION	HABITAT
Balsaminaceae		
Impatiens biflora Walt.	B, S	wet ditch, wet woods, creek bank
Vitaceae		
Parthenocissus quinquefolia (L.) Planch.	B	low shady wet woods
P. vitacea (Knerr.) Hitchc.	B, S	open woods, creek bank
Tiliaceae		
Tilia americana L.	B, S	rich mesic woods, edge of wet woods, field
Hypericaceae		
Hypericum majus (Gray) Britt.	B, S	roadside, bog edge, wet woods, wet meadow
H. perforatum L.	B	ditch, sand
Triadenum fraseri (Spach) Gl.	S	wet ditch
Violaceae		
Viola adunca Sm.	S	roadside, sand
V. conspersa Reich.	B, S	open woods, old field
V. cucullata Xit.	B, S	creek bank, moist woods, clay
V. novae-angliae House	B	moist open hardwoods
V. pubescens Ait.	B, S	creek bottom, hardwood swamp, shady woods, clay
V. renifolia Gray	B	creek bottom, moist shady woods, sand
V. sororia Willd.	B	creek bottoms
Thymelaceae		
Dirca palustris L.	S	dry to mesic woods
Onagraceae		
Ciraea alpina L.	B, S	shady hardwood swamp, cedar swamp (uncommon)
C. quadrisulcata (Maxim) Franch. and Sav.	B	creek bank, sand
Epilobium angustifolium L.	B, S	roadside, ditch, clay
E. ciliatum Raf.	S	wet ditch
Oenothera biennis L.	B, S	roadside, railroad ballast

SPECIES	LOCATION	HABITAT
Araliaceae		
Aralia hispida Vent.	B	railroad ballast, gravel (uncommon)
A. nudicaulis L.	B, S	shady woods, open oak woods
A. racemosa L.	B	shady hardwood swamp
Panax trifolium L.	B, S	shady hardwood swamp, moist deciduous woods
Umbellifereae		
Carum carvi L.	B, S	old farmyard, old field, clay
Cicuta maculata L.	B, S	roadside ditch, wet woods, clay
Heracleum lanatum Michx.	B, S	creek bank, hardwood swamp, clay
Osmorhiza claytonia (Michx.) C.B. Clarke	B, S	hardwood swamp, wet shady woods, creek bottoms
O. longistylis (Torr.) D.C.	S	shady hardwood swamp
Sanicula marilandica L.	B, S	wet shrubby ditch, open woods
Sium suave Walt.	B	rich woods, woodland pool
Cornaceae		
Cornus alternifolia L.	B, S	rich woods, creek bank (uncommon)
C. canadensis L.	B, S	mesic woods, old field
C. racemosa Lam.	S	shrubby woods edge
C. rugosa Lam.	S	shady oak woods, sand
C. stolonifera Michx.	B, S	open field, creek bed, open woods, clay
Ericaceae		
Arctostaphylos uva-ursi (L.) Spreng.	S	roadside, sand
Chamaedaphne calyculata (L.) Moench	B*, S	bog edge, sand
Chimaphila umbellata (L.) Bart.	B	rich, shady woods
Gaultheria hispidula (L.) Muhl.	B	shady conifer swamp
G. procumbens L.	S	dry open woods, sand
Kalmia polifolia Wang.	B	bog edge
Ledum groenlandicum Oeder.	B, S	bog edge, conifer swamp
Moneses uniflora (L.) Gray	S	shady birch/fir woods (uncommon)

SPECIES	LOCATION	HABITAT
Monotropa uniflora L.	B, S	shady dense woods, creek bank
Pyrola asarifolia Michx.?	B, S	moist shady woods, creek bank
P. elliptica Nutt.	B, S	moist open woods
P. rotundifolia L.?	S	shady conifer woods (uncommon)
P. secunda L.	S	shady conifer woods
Vaccinium angustifolium Ait.	B, S	moist woods, conifer swamp
V. myrtilloides Michx.	S	open woods, clay
V. oxycoccos L.	B	conifer swamp
Primulaceae		
Lysimachia ciliata L.	B, S	roadside ditch, wet meadow, shady hardwood swamp
L. thrysiflora L.	B	dense alder swamp
Trientalis borealis Raf.	B, S	rich shady woods, creek bottoms
Oleaceae		
Fraxinus nigra Marsh.	B, S	hardwood swamp, creek bottoms
F. pennsylvanica Marsh.	B	creek bottoms, clay
Gentianaceae		
Halenia deflexa (Sm.) Griseb.	S	path in open woods (uncommon)
Apocynaceae		
Apocynum androsaemifolium L.	B, S	roadside, railroad tracks, old field
Asclepiadaceae		
Asclepias exaltata L.	B	railroad tracks bank, sand (uncommon)
A. ovalifolium Decnė.	S	railroad tracks
A. syriaca L.	B, S	roadside, railroad tracks, sand, clay
Convolvulaceae		
Convolvulus sepium L.	S	roadside, sand
C. spithameus L.	B, S	pine woods, ditch along railroad tracks, sand
Polemoniaceae		
Collomia linearis Nutt.	B	slope below railroad tracks, clay

SPECIES	LOCATION	HABITAT
Boraginaceae		
Cynoglossum boreale Fern.	S	oak woods, sand (uncommon)
Myosotis scorpioides L.	B	alder swamp, creek bank
Verbenaceae		
Verbena hastata L.	B	roadside ditch, wet meadow
Labiate		
Galeopsis tetrahit L. var. *bifida* (Boenn.) Lej. and Court.	B, S	wet ditch, creek bank, open moist woods
Glecoma hederacea L.	B, S	pasture, grazed woods, grazed creek bottom
Lycopus americanus Muhl.	B, S	wet ditch, wet woods
L. uniflorus Michx. (?)	B, S	wet ditch, open swamp, sand
Mentha arvensis L.	B, S	open wet disturbed area, creek bottoms
Prunella vulgaris L.	B, S	bare clay, pasture, railroad ballast
Scutellaria galericulata L.	B, S	wet ditch, alder swamp, marsh
S. lateriflora L.	B, S	wet ditch along railroad tracks, creek bottoms, sand
Stachys palustris L.	B, S	roadside ditch, creek bank, open popple woods
Solanaceae		
Physalis heterophylla Nees.	S	roadside, clay
Solanum dulcamara L.	B, S	open wet woods, disturbed creek bottoms
Scrophulariaceae		
Agalinis tenuifolia (Vahl.) Raf.	B	roadside ditch, sand
Castilleja coccinea (L.) Spreng.	B, S	wet meadow, roadside ditch, clay
Chaenorrhinum minus (L.) Lange	B	railroad ballast (uncommon)
Chelone glabra L.	S	wet roadside ditch
Gratiola neglecta Torr.	S	wet ditch
Linaria vulgaris Hill.	B, S	roadside, sand, clay, gravel
Mimulus ringens L.	S	shady creek bank, clay (uncommon)

SPECIES	LOCATION	HABITAT
Scrophularia lanceolata Pursh.	B	creek bank, roadside, sand
Verbascum thapsus L.	B, S	roadside, clay
Veronica longifolia L.	B	road bank, clay
V. peregrina L.	B, S	roadside ditch, open wet area in woods
V. serpyllifolia L.	B	lawn weed
Lentibulariaceae		
Utricularia cornuta Michx.	S	open shallow water in bog (uncommon)
U. intermedia Hayne	S	open shallow water in bog (uncommon)
Plantaginaceae		
Plantago major L.	B, S	center strip, dirt road, clay and gravel
P. patogonica Jacq.	S	roadside, gravel (uncommon)
Rubiaceae		
Galium asprellum Michx.	S	lowland hardwoods
G. boreale L.	S	railroad tracks, gravel
G. tinctorium L.	S	wet ditch
G. trifidum L.	S	wet ditch
G. triflorum Michx.	B, S	creek bottoms, open woods, roadside, sand
Caprifoliaceae		
Diervilla lonicera Mill.	B, S	roadside, old field, sand
Linnaea borealis L.	B, S	open to shady mesic woods, conifer swamp
Lonicera canadensis Marsh.	B, S	mixed hardwoods, partly shady, sand
L. dioica L.	S	creek bottoms, roadside, clay
L. hirsuta Eat.	B, S	shady young woods
L. tatarica L.?	S	wet roadside ditch
Sambucus pubens Michx.	B, S	shady hardwoods swamp, roadside/ woods edge
Symphoriocarpus albus (L.) Blake.	S	roadside bank
Viburnum lentago L.	B, S	old field, clay
V. opulus L.	S	mesic woods, roadside ditch
V. rafinesquianum Schultes	B, S	roadside, old field, open woods, clay

SPECIES	LOCATION	HABITAT
V. trilobum Marsh.	B, S	woods edge, hardwood swamp
Cucurbitaceae		
Echinocystic lobata (Michx.) T. and G.	B	creek bank (uncommon)
Campanulaceae		
Campanula aparinoides Pursh.	S	shady hardwood swamp
C. rotundifolia L.	B	old field (uncommon)
Lobelia inflata L.	B	sandy ditch
Compositeae		
Achillea millefolium L.	B, S	roadside, railroad tracks, sand, gravel
Ambrosia artemisiifolia L.	B, S	roadside, sand, gravel, clay
A. psilostachya DC.	S	moist, disturbed soil, clay
Artemisia ludoviciana Nutt.	S	old field
Anaphalis margaritaceae (L.) Benth. and Hook	B, S	creek bank, old field, open woods
Antennaria neglecta Greene	B, S	old field
A. neodica Greene	B	old field
A. plantaginifolia Mitt.	B	old field
Artemesia biennis Willd.	B	roadside, sand
A. caudata Michx.	B	roadside, sand
A. serrata Nutt.	S	creek bank, dense vegetation
Aster ciliolatus Lindl.	B, S	roadside, old field, wet meadow, open woods
A. ericoides L.	B	dry bare slope, clay
A. lateriflorus (L.) Britt.	B	woods/field edge
A. macrophyllus L.	B, S	moist roadside ditch, open woods
A. pilosus Willd.	B, S	wet ditch, old field, sand
A. puniceus L.	B, S	wet ditch, old field, sand
A. simplex Willd.	B, S	roadside bank, wet ditch, creek bank
A. umbellatus Mill.	B, S	wet ditch, creek bank, wet woods
Bidens cernua L.	S	bog edge, creek bank, clay
B. frondosa L.	B	roadside, sand, bare clay banks

SPECIES	LOCATION	HABITAT
B. tripartita L.	S	bog edge, peat
Chrysanthemum leucanthemum L.	B*, S	old field, clay
Cirsium arvense (L.) Scop.	B, S	roadside ditch, old field
C. muticum Michx.	B, S	wet ditch, sand
C. vulgare (Savi) Tenore	B, S	roadside, sand, clay
Conyza canadensis (L.) Cronq.	S	roadside, gravel
Crepis tectorum L. ?	S	old field
Erigeron anuus (L.) Pers.	B, S	old field, shady mesic woods, clay
E. philadelphicus L.	B, S	roadside, bank, woods path, creek bank, open woods, clay
Eupatorium maculatum L.	B, S	wet roadside ditch, hardwood swamp
E. perfoliatum L.	B	wet ditch, sand
Gnaphalium uliginosum L.	B, S	wet ditch, roadside, clay
Helianthus annuus L.	B	disturbed road, sand
H. decapetalis L. (?)	S	edge of wet, shady woods
H. giganteus L.	B, S	wet roadside ditch, old field, edge of wet woods, sand
H. maximiliani Schrad.	B	old field, clay
H. strumosus L.	B, S?	moist roadside ditch, sand, wet woods, edge of bog
Heliopsis helianthoides (L.) Sweet ?	B	old field, clay
Hieracium aurantiacum L.	B, S	roadside, creek bank below railroad tracks
H. florentinum All.	B, S	roadside, old field
H. pratense Tausch.	B, S	roadside, disturbed gravel berm, sand, gravel
Lactuca binennis (Moench.)	B, S	roadside, railroad tracks, field/woods edge, shady hardwood swamp
L. canadensis L.	B, S	dry ditch, old field, woods edge, clay
Liatris aspera Michx.	S	roadside, sand
L. pycnostachya Michx.?	S	bank above railroad tracks, clay
Matrecaria matricarioides (Less.) Porter	B, S	roadside, sand, gravel
Petasites frigidus (L.) Fries.	B, S	wet ditch, open woods, rich swamp woods

SPECIES	LOCATION	HABITAT
P. sagittatus (Pursh.) Gray	B	culvert ditch, clay
Prenanthes alba L.	B, S	wet ditch, creek bank, shady hardwoods
Rudbeckia hirta L.	B, S	wet meadow, ditch along railroad tracks
R. laciniata L.	B, S	moist roadside ditch, wet creek bank, sand, clay
R. pinnata (Vent.) Barnh.	S	unused road, dry clay
Senecio aureus L.	B, S	wet ditch, wet shady wood, hardwood swamp (uncommon)
S. pauperculus Michx.	B, S	old field, oak woods, creek bottom, sand, clay
Solidago canadensis L.	B	dry old field
S. flexicaulis L.	B, S	shady creek bottoms
S. gigantea Ait.?	S	old field
S. graminifolia (L.) Salisb.	B, S	roadside ditch, bog edge, sand
S. juncea Ait.	B, S	dry old field, sand (uncommon)
S. nemoralis Ait.	B, S	roadside, dry old field, clay
S. uliginosa Nutt.	B, S	creek bank, bog
Sonchus oleraceus L.	B	roadside ditch, wet meadow
Tanacetum vulgare L.	B, S	disturbed parking area, roadside bank, clay
Taraxacum officinale Web.	B, S	roadside, old field, clay
Tragopogon dubius Scop.	B, S	roadside, railroad ballast, old field, clay

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APPENDIX II

COMMUNITY DESCRIPTION

I. Aspen Hardwoods

This forest type is the least mature of the northern forest communities and is found in areas of heavy soil where previous growth has been removed by clear-cutting or fire. The area within the Little Balsam Basin north of Douglas County B is primarily of this type. The largest area in the Skunk is in the northeast corner of the basin, north of the creek and east of Highway 103. It is characterized by a dense stand of young, even-aged trees, a full component of shrub species and a ground cover of primarily weedy invaders. The major tree is the quaking aspen or popple (Populus tremuloides), a pioneering species which produces abundant wind carried seeds, germinates well on moist open soil and grows rapidly for several years until checked by shading.

Accompanying aspen on the drier sites but less common is the paper birch (Betula papyrifera), a species autecologically similar to popple and a member, at some stage, of all the northern hardwood forest types. Basswood (Tilia americana), ash (Fraxinus sp.) and red maple (Acer rubrum) are found as samplings in the understory.

The shrub component is similar to the shrub stands found in other areas, being dominated by red osier dogwood (Cornus stolonifera) and with equal portions of hazel (Corylus sp.), willow (Salix sp.), roses (Rosa sp.), juneberries (Amelanchier sp.) and Viburnums (Viburnum sp.).

Ground cover consists of grasses, sedges, rushes (Juncus sp. and Luzula sp.) and the invading species of roses (Potentilla sp., Fragaria sp. and Geum sp.) and composites such as (Hieracium sp. and Taraxacum sp.)

II. Northern Hardwoods

A. Aspen/Birch: This community occurs on the heavier soils south of Douglas County B and west of Patzau in the Little Balsam. It dominates the southern half of Skunk Creek. It appears to be a successional stage between the aspen hardwoods previously described and the northern hardwoods discussed below. Aspen (Populus tremuloides) and paper birch (Betula papyrifera) remain major component species but the more shade tolerant species appear in greater numbers and as a higher proportion of the whole. Of these sugar maple (Acer saccharum), balsam fir (Abies balsamea) and ash (Fraxinus sp.) are equally abundant with red maple (Acer rubrum), basswood (Tilia americana) and red oak (Quercus borealis) being of lesser importance.

The hazels (*Corylus americana* and *C. cornuta*) dominate the shrub layer which includes saplings of the major trees, mountain maple (*Acer spicatum*) and black alder (*Ilex verticillata*).

Ground layer species are similar in this and the two following hardwood groups. Their occurrence is related primarily to soil moisture, available nutrients and total insolation. Common here are bunchberry (*Cornus canadensis*), Canada anemone (*Anemone quinquefolia*), twisted stalk (*Streptopus* sp.), wild sarsaparilla (*Aralia nudicaulis*), black snakeroot (*Sanicula marilandica*) and blueberry (*Vaccinium angustifolia*).

II. Northern Hardwoods

B. Oak/Maple: This forest type is fairly common on the lighter soils in the central and southwest part of the Little Balsam. It occurs as scattered woodlots on the sandy soils of the northwest corner of Skunk Creek Basin. It is a moderately mature woodland with fewer and larger trees than in either of the previously described communities.

Aspen is present only in greatly reduced numbers and species characteristic of mesic and dry mesic sites predominate. Paper birch (*Betula papyrifera*) is dominant with red maple (*Acer rubrum*), sugar maple (*Acer saccharum*) and red oak (*Quercus borealis*) all common.

Fewer shrubs grow in the shady understory. Instead, this area is a nursery for samplings of the mesic species.

The herbaceous layer is composed of light loving forbes that flower in later spring, including all of the herbs mentioned in the previous grouping as well as wintergreen (*Gaultheria procumbens*), wild oats (*Uvularia sessilifolia*) and a dense layer of bracken fern (*Pteridium aquilinum*).

II. Northern Hardwoods

C. Maple/Basswood: Communities of this type are restricted to small areas of rich moist soil in the west portion of the Little Balsam. A few small areas occur in the northwest corner of the Skunk Creek Basin. Trees are mature, widely spaced with a broad branching pattern which forms a closed canopy.

Sugar maple (*Acer saccharum*) is the major tree species with red maple (*Acer rubrum*) and basswood (*Tilia americana*) common, and ironwood (*Ostrya virginiana*), paper birch (*Betula papyrifera*), white ash (*Fraxinus americana*) and balsam fir (*Abies balsamea*) also present.

Low light limits shrub growth. Those shrubs present are small and few in number, and include low evergreen vines such as bunchberry (*Cornus canadensis*) and twinflower (*Linneae borealis*). Beaked hazel (*Corylus cornuta*), currents (*Ribes* sp.) and Viburnum (*Viburnum* sp.) are also present.

Herbaceous cover is rich with spring flowering forbes being dominant. Commonly occurring species include wild lily-of-the-valley (*Maianthemum canadense*), starflower (*Trientalis borealis*), bedstraw (*Galium triflower*), rice grass (*Oryzopsis* sp.) and the sedge (*Carex pensylvanica*.

III. Conifers

This unusual community probably results from human disturbance at least in so far as selective cutting is involved. (It covers a moderately small area in the west central part of T46N, R15W, sec 3, west of the creek.) The soil is dry but heavy; the slope gentle. Species diversity is low but the trees are relatively mature and dense. The major species is white spruce (*Picea glauca*), grading into a mixed popple (*Populus tremuloides*)/spruce woods nearer the creek.

Shrub growth is minimal in the denser woods, but as the trees thin out toward the hilltop the hazels (*Corylus* sp.) and alder (*Alnus rugosa*) become increasingly common with some red osier dogwood (*Cornus stolonifera*) and willow (*Salix* sp.) present.

Within the community itself the ground is bare in most spots except for a thick duff of needles. Little other than sparse grass, bunchberry (*Cornus canadensis*) and large leaved aster (*Aster macrophyllus*) is present.

The conifer communities in the Skunk Creek Basin are dominated by balsam fir. The largest areas are in the extreme southwest corner of the basin and northeast of the junction of Carlton County 5 and Carlton County 6.

IV. Ravine

This association does not represent a coherent community of plants as much as a collection of species with similar tolerances growing in a very specialized and restricted area: the steep slopes along the creek in the central section of the basins. The location is cool, moist and shady. The ravine forest grades into northern hardwoods of the upland and the swamp woods of the creek bottoms and has species in common with each.

Several tree species are common, with balsam fir (*Abies balsamea*) being visually the most abundant, followed by sugar maple (*Acer saccharum*), American elm (*Ulmus americana*), black ash (*Fraxinus nigra*), aspen (*Populus tremuloides*) and red maple (*Acer rubrum*).

The shrub layer is quite rich and dense consisting about equally of young balsam fir and alder (*Alnus rugosa*), with saplings of the major trees, some hazel (*Corylus* sp.) and red osier dogwood (*Cornus stolonifera*).

Ground cover is rich and unique including pink pyrola (*Pyrola asarifolia*), spotted coralroot (*Corallorhiza maculata*), wood nettle (*Laportea canadensis*), and wild ginger (*Asarum canadense*), along with many species from rich woods and bottomlands.

V. Conifer Plantations

Pine plantations are found at several sites in the Little Balsam Creek Basin, all of limited extent. Small plantations are scattered throughout the Skunk Creek Basin adjacent to agricultural fields. They occur in agricultural areas, are fairly mature and probably result from an attempt to manage unprofitable fields for forest improvement or soil conservation. Red pine is chosen because it grows quickly, requires little care, and is relatively disease free. Dense planting, a heavy duff of fine needles and increasingly acid soil prevent colonization of shrub and herb species.

VI. Hardwood Swamp

The swamps of this type sampled were primarily in the southern third of the Little Balsam Basin. Large areas of swamp exist northwest of the Soo Line tracks in the Skunk Creek Basin, with smaller areas along the creek itself. They exist on pockets of peaty soil in depressions and grade directly into northern hardwood communities on the upland.

Conditions are relatively severe and species diversity is limited. Black ash (*Fraxinus nigra*) is the major species present. These trees are quite widely spaced and mature with thick trunks and narrow crowns. Present in much smaller numbers in the drier areas are balsam fir (*Abies balsamea*) and paper birch (*Betula papyrifera*).

Ash saplings and mountain maple (*Acer spicatum*) dominate the shrub layer with saplings of balsam fir and american elm (*Ulmus americana*), gooseberries (*Ribes* sp.) and hazel (*Corylus* sp.) present in moderate numbers as well.

The ground cover is rich and diverse as the ashes admit light late into the spring. Ferns and sedges are abundant and the uneven terrain among the ash roots provides habitat for many forbes. Common among these are goldthread (*Coptis trifolia*), naked mitrewort (*Mitella nuda*), dwarf blackberry (*Rubus pudescens*) and the violets (*Viola* sp.)

VII. Conifer Swamp

This cover type, with the hardwood swamp, occupies a large and relatively inaccessible portion of the southern half of the Little Balsam Creek Basin. The largest area in the Skunk Creek Basin is drained by the northern fork of the creek, with a few smaller areas along other branches. It is found on heavy, wet soils and probably indicates a successional stage between the wetter black spruce/tamarack swamps and the maple/basswood community of the northern hard-woods type.

The leading dominants are white cedar (*Thuja occidentalis*) and balsam fir (*Abies balsamea*) with cedar occurring both in dense single species stands and scattered throughout the canopy. Black ash (*Fraxinus nigra*), American elm (*Ulmus americana*) and yellow birch (*Betula lutea*) occur with less frequency. Sugar and red maple (*Acer saccharum* and *A. rubrum*) may occur as seedlings or saplings.

The understory consists primarily of plants tolerant of low light levels: mosses, ferns, sedges, grasses and some Ericaceous shrubs.

VIII. Bogs

Bogs as considered here include a gradient of communities from a sedge-shrub mat around open water to a closed woodland of acid tolerant conifers. This community type is found in patches in depression in the southwest corner of the Little Balsam Creek Basin and grades to both shrub wetlands and conifer swamps. The two bogs in the Skunk Creek Basin are 1/4 mile east of Carlton County 5. Its extent is limited because very specific geologic, hydrologic and environmental factors are necessary for its formation. The major species composing a bog mat are the *Sphagnum* mosses, the sedges (*Carex* sp., *Eriophorum* sp. and *Scirpus* sp.) and the Ericaceous shrubs such as leather leaf (*Chamaedaphne calyculata*), bog laurel (*Kalmia polifolia*) and Labrador tea (*Ledum groenlandicum*). Blueberries (*Vaccinium angustifolium*) and cranberries (*V. oxycoccos*) may also occur, as may members of the orchid and lily families. The shrub margin may consist of alder (*Alnus* sp.) supplemented by shrubs more restricted to bog habitats such as black alder (*Ilex verticillata*) and the mountain holly (*Nemapanthus mucronata*).

Black spruce (*Picea mariana*) and tamarack (*Larix laricina*) are the major tree species present. While they sometimes occur together, more frequently tamarack will occupy the young advancing edge of the bog while spruce rings it on the landward side and fills the older, firmer peat basins. Seedlings and saplings of some mesic species, sugar maple (*Acer saccharum*) and white pine (*Pinus strobus*) may also occur.

IX-A. Marsh

Marshes are found uncommonly only in the Skunk Creek Basin and are generally too small to show on the map. They occur along cleared portions of the creek bottom, adjacent to roadside and railroad right of ways and along the margin of small ponds. Sedges (*Carex* sp.) are very common as are some grasses (*Calamogrostis* sp. and *Glyceria canadensis*). Less commonly encountered species include cattails (*Typha* sp.), water hemlock (*Cicuta maculata*), knotweed (*Polygonum* sp.), blueflag (*Iris* sp.), mints (*Lycopus* sp. and *Mentha* sp.) and Joe-Pye weed (*Eupatorium maculatum*).

IX-B. Wet Shrublands

This community is relatively common in the moist open areas of the central, more heavily settled portion of the Little Balsam Creek Basin but are nowhere extensive. In the Skunk Creek Basin it occurs along the upper reaches of the creek branches. Roadside ditches, old fields on clay soils, creek bottomlands and banks, beaver meadows and bog and conifer swamp margins all may show the species component characteristic of this community.

The major species present are the alders (*Alnus rugosa*) and the willows (*Salix* sp.). Density increases in proportion to increasing soil moisture, as does the diversity of the flora. The wetter thickets have an understory of marsh species including ferns, mints (*Mentha arvensis*, *Lycopus uniflorus* and *Scutellaria galericulata*), bedstraws (*Galium* sp.) and other weak stemmed species such as jewelweed (*Impatiens biflora*) and arrowleaf tearthumb (*Polygonum sagittatum*). Herbs in the drier stands resemble wet meadow species with grasses, sedges, *Iris* and composites all occurring frequently.

X. Abandoned Fields

Many fields in the central inhabited area of the Little Balsam Creek Basin have been removed from cultivation and are producing a weedy, forbes-dominated hay. The more recently abandoned areas (group A) produce primarily herbaceous vegetation; woody vegetation has begun to invade lands in disuse (group B). In the Skunk Creek Basin both areas occur on the margins of active fields, primarily in the northern half of the basin along Carlton County 6. Each is characterized by a large number of species with blooming times spanning the growing season. Most of the weedy species on the floristic list (Appendix I) are found in abandoned fields as well as in the more recently disturbed areas such as roadsides, ditches, railroad tracks and yards. Typical late spring forbes include buttercup (*Ranunclus acris*), yellow rocket (*Barbarea vulgaris*), strawberry (*Fragaria virginiana*), pussy-toes (*Antennaria* sp.) and sorrel (*Rumex acetosella*). Through the summer and early fall composites dominate. Common among these are the oxeye daisy (*Chrysanthemum leucanthemum*), Devil's paintbrush (*Hieracium aurantiacum*), pearly everlasting (*Anaphalis margaritacea*) and the abundant old field goldenrod (*Solidago nemoralis*). Herb cover of the shrubby old fields (group B) is very similar since the shrub cover rarely is dense enough to affect the penetration of sunlight or precipitation. The invading shrubs are thin stemmed and rarely over 8 feet tall. Typical species are red osier dogwood (*Cornus stolonifera*), the viburnums (*Viburnum lentago*, *V. rafinesquianum* and *V. trilobum*), the hawthorns (*Cratequs* sp.) and the juneberries (*Amelanchier* sp.).

XI-A. *Agricultural*

These include the hayed fields and cultivated fields in the immediate vicinity of Patzau, Little Balsam Creek Basin. Fields in the Skunk Creek Basin occur primarily in the northern half of the basin along Carlton County 6. The hay fields are similar in species composition to the abandoned fields discussed in Section X, but with a lower diversity and a higher percentage of legumes: (*Trifolium pratense*, *T. repens*, *T. hybridum*, *Melilotus alba*, *M. officianalis* and *Medicago sativa*). Species avoided by livestock tend to increase in grazed fields and include the docks (*Rumex* sp.), thistles (*Cirsium* sp.) and tansy (*Tanacetum vulgare*). Some of the cultivated crop grains such as rye, oats and wheat may appear as isolated plants or in scattered patches.

XI-B. *Pastures*

The main pastureland in the Skunk Creek Basin in the sheep farm south of Elim Church on Carlton County 6 and north of the Soo Line railroad tracks. A few smaller areas occur adjacent to active fields along Carlton County 6. Like the abandoned fields, these areas support many grasses such as quickgrass (*Agropyron* sp.), red top (*Agrostis* sp.), timothy (*Phleum pratense*) and bluegrass (*Poa* sp.). However, they differ from the fields in supporting a higher abundance of "weedy" broad-leaved species such as the thistle (*Cirsium* sp.), dock (*Rumex* sp.) and tansy (*Tanacetum vulgare*).

APPENDIX III

SAMPLING SUMMARIES OF WOODY VEGETATION FOR THE LITTLE BALSAM CREEK BASIN

Table 1. Density and Frequency of Trees Sampled in Northern Hardwood (Aspen-Birch Type) Forest (n=300).

Species	Density	Frequency	Relative Dominance	Relative Density	Relative Frequency	Importance
Populus tremuloides Michx.	64.97	40.00	23.32	15.33	14.15	17.60
Betula papyrifera Marsh.	66.38	49.33	13.81	15.67	17.45	15.64
Acer saccharum Marsh.	59.32	44.00	8.99	14.00	15.57	12.85
Abies balsamea (L.) Mill.	57.91	29.33	10.79	13.67	10.38	11.61
Fraxinus nigra Marsh.[1/]	52.26	28.00	10.77	12.33	9.91	11.00
Acer rubrum L.	39.55	30.67	6.06	9.33	10.85	8.75
Tilia americana L.	31.07	20.00	7.19	7.33	7.08	7.20
Quercus borealis Michx. f.	19.77	14.67	7.07	4.67	5.19	5.64

(Density: 423.7 trees/hectare; mean diameter = 19.8 cm; mean Point-to-Tree Distance = 4.9m)

Table 2. Density and Frequency of Trees Sampled in Northern Hardwood (Oak-Maple Type) Forest (n=300).

Species	Density	Frequency	Relative Dominance	Relative Density	Relative Frequency	Importance
Betula papyrifera Marsh.	132.78	52.00	23.91	30.00	22.29	25.40
Acer rubrum L.	79.67	41.33	11.79	10.00	17.71	15.84
Acer saccharum Marsh.	61.97	37.33	15.17	14.00	16.00	15.06
Quercus borealis Michx. f.	44.26	25.33	20.11	10.00	10.86	13.66
Populus tremuloides Michx.	29.51	17.33	9.51	6.67	7.43	7.87
Abies balsamea (L.) Mill.	30.99	20.00	4.98	7.00	8.57	6.85
Fraxinus nigra Marsh.	25.08	12.00	4.38	5.67	5.14	5.06

(Density = 442.6 trees/hectare; mean diameter = 19.8 cm; mean Point-to-Tree Distance = 4.8m)

Table 3. Density and Frequency of Trees Sampled in Ravine Forests (n=200)

Species	Density	Frequency	Relative Dominance	Relative Density	Relative Frequency	Importance
Acer saccharum Marsh.	26.47	36.00	18.15	10.00	13.33	13.83
Ulmus americana L.	27.79	24.00	21.18	10.50	8.89	13.52
Fraxinus nigra Marsh.	42.35	32.00	10.27	16.00	11.85	12.71
Abies balsamea (L.) Mill.	41.03	38.00	7.25	15.50	14.07	12.27
Populus tremuloides Michx.	31.76	36.00	10.44	12.00	13.33	11.93
Acer rubrum L.	29.17	30.00	9.09	11.00	11.11	10.40
Populus balsamifera L.	26.47	22.00	7.94	10.00	8.15	8.69
Tilia americana L.	15.88	16.00	6.68	6.00	5.93	6.20

(Density = 264.7 trees/hectare; mean diameter = 20.5 cm; mean Point-to-Tree Distance = 6.2m)

Table 4. Density and Frequency of Trees Sampled in Wetland Hardwoods (n=40).

Species	Density	Frequency	Relative Dominance	Relative Density	Relative Frequency	Importance
Fraxinus nigra Marsh.	349.48	70.00	61.38	57.50	36.84	51.91
Abies balsamea (L.) Mill.	136.75	50.00	14.93	22.50	26.32	21.25
Betula papyrifera Marsh.	45.56	30.00	8.00	7.50	15.79	10.43
Populus tremuloides Michx.	30.39	10.00	6.43	5.00	5.26	5.56

(Density = 607.8 trees/hectare; mean diameter = 18.6 cm; mean Point-to-Tree Distance = 4.1m)

Table 5. Density and Frequency of Trees Sampled in Coniferous Stands (n=60).

Species	Density	Frequency	Relative Dominance	Relative Density	Relative Frequency	Importance
Picea glauca (Moench) Voss.	96.85	66.67	40.22	40.00	32.26	37.49
Populus tremuloides Michx.	68.60	53.33	32.04	28.33	25.81	28.73
Betula papyrifera Marsh.	20.18	20.00	3.11	8.33	9.68	7.04
Pinus resinosa Ait.	12.11	13.33	3.81	5.00	6.45	5.08

(Density = 242.1 trees/hectare; mean diameter = 2.12 cm; mean Point-to-Tree Distance = 6.4m)

Table 6. Density and Frequency of Trees Sampled in Aspen Hardwoods (n=240).

Species	Density	Frequency	Relative Dominance	Relative Density	Relative Frequency	Importance
Populus tremuloides Michx.	159.07	95.00	74.67	76.25	56.44	69.12
Betula papyrifera Marsh.	24.34	28.33	11.26	11.67	16.33	13.25
Ulmus americana L.	7.82	15.00	2.54	3.75	8.91	5.07

(Density = 208.7 trees/hectare; mean diameter = 17.0 cm; mean Point-to-Tree Distance = 6.9m)

Table 7. Density and Frequency of Shrubs Sampled in Northern Hardwood (Aspen-Birch Type) Forests (15 Quadrats).

Species	Density	Frequency	Relative Density	Relative Frequency	Importance
Corylus americana Walt.	1.95	.47	29.38	10.77	40.15
Acer rubrum L.	.49	.67	7.44	15.38	22.83
Corylus cornuta Marsh.	.95	.33	14.29	7.69	21.98
Populus tremuloides Michx.	.63	.47	9.46	10.77	20.23
Acer saccharum Marsh.	.60	.47	9.05	10.77	19.82
Acer spicatum Lam.	.40	.47	6.04	10.77	16.81
Abies balsamea (L.) Mill.	.16	.33	2.41	7.69	10.11
Ilex verticillata (L.) Gray.	.32	.07	4.83	1.54	6.37
Alnus rugosa (DuRoi) Spreng.	.21	.13	3.22	3.08	6.30
Corylus americana Walt.	.31	.07	4.63	1.54	6.17

Table 8. Density and Frequency of Shrubs Sampled in Northern Hardwood (Oak-Maple Type) Forest (15 Quadrats).

Species	Density	Frequency	Relative Density	Relative Frequency	Importance
Acer saccharum Marsh.	3.39	.53	46.01	13.79	59.81
Acer rubrum L.	.67	.73	9.06	18.97	28.02
Corylus cornuta Marsh.	1.12	.40	15.22	10.34	25.56
Corylus americana Walt.	.88	.20	11.96	5.17	17.13
Acer spicatum Lam.	.24	.47	3.26	12.07	15.33
Abies balsamea (L.) Mill.	.24	.27	3.26	6.90	10.16
Populus tremuloides Michx.	.28	.13	3.80	3.45	7.25
Fraxinus nigra Marsh.	.04	.20	.54	5.17	5.72

Table 9. Density and Frequency of Shrubs Sampled in Ravine Forests (10 Quadrats).

Species	Density	Frequency	Relative Density	Relative Frequency	Importance
Abies balsamea (L.) Mill.	1.60	.70	25.40	12.73	38.12
Alnus rugosa (DuRoi) Spreng.	1.22	.70	19.37	12.73	32.09
Corylus cornuta Marsh.	.54	.40	8.57	7.27	15.84
Cornus stolonifera Michx.	.36	.40	5.71	7.27	12.99
Fraxinus nigra Marsh.	.36	.40	5.71	7.27	12.99
Acer spicatum Lam.	.46	.30	7.30	5.45	12.76
Acer saccharum Marsh.	.26	.40	4.13	7.27	11.40
Tilia americana L.	.16	.30	2.54	5.45	7.99
Acer rubrum L.	.08	.30	1.27	5.45	6.72
Corylus americana Walt.	.18	.20	2.86	3.64	6.49
Ostrya virginiana (Mill.)K.Koch	.16	.20	2.54	3.64	6.18

Table 10. Density and Frequency of Shrubs Sampled in Wetland Hardwood Forests (2 Quadrats).

Species	Density	Frequency	Relative Density	Relative Frequency	Importance
Acer spicatum Lam.	1.20	1.00	26.67	20	46.67
Fraxinus nigra Marsh.	1.10	1.00	24.44	20	44.44
Abies balsamea (L.) Mill.	.60	1.00	13.33	20	33.33
Ribes sp.	.70	.50	15.56	10	25.56
Ulmus americana L.	.40	.50	8.89	10	18.89
Corylus cornuta Marsh.	.30	.50	6.67	10	16.67
Alnus rugosa (DuRoi) Spreng.	.20	.50	4.44	10	14.44

Table 11. Density and Frequency of Shrubs Sampled in Coniferous Stands (3 Quadrats).

Species	Density	Frequency	Relative Density	Relative Frequency	Importance
Corylus americana Walt.	3.67	.33	27.23	5	32.23
Corylus cornuta Marsh.	2.47	.33	18.32	5	23.32
Alnus rugosa (DuRoi) Spreng.	1.60	.67	11.89	10	21.88
Fraxinus nigra Marsh.	.53	1.00	3.96	15	18.96
Cornus sp.	1.40	.33	10.40	5	15.40
Rosa sp.	.33	.67	2.48	10	12.48
Cornus stolonifera Michx.	.93	.33	6.93	5	11.93
Salix sp.	.93	.33	6.93	5	11.93
Abies balsamea (L.) Mill.	.13	.67	.99	10	10.99
Picea glauca (Moench) Voss.	.60	.33	4.46	5	9.46
Virbunum sp.	.33	.33	2.48	5	7.48
Rubus sp.	.27	.33	1.98	5	6.98
Ribes sp.	.13	.33	.99	5	5.99
Acer saccharum Marsh.	.07	.33	.50	5	5.50
Populus tremuloides Michx.	.07	.33	.50	5	5.50

Table 12. Density and Frequency of Shrubs Sampled in Aspen Hardwood Forests (12 Quadrats).

Species	Density	Frequency	Relative Density	Relative Frequency	Importance
Cornus stolonifera Michx.	2.40	.92	29.09	15.49	44.58
Populus tremuloides Michx.	.93	.92	11.31	15.49	26.81
Corylus cornuta Marsh.	.68	.50	8.28	8.45	16.73
Salix sp.	.57	.58	6.87	9.86	16.73
Rosa sp.	.55	.33	6.67	5.63	12.30
Amelanchier sp.	.40	.42	4.85	7.04	11.89
Corylus americana Walt.	.58	.25	7.07	4.23	11.30
Viburnum sp.	.47	.33	5.66	5.63	11.29
Viburnum rafinesquianum Schult.	.50	.17	6.06	2.82	8.88
Tilia americana L.	.23	.25	2.83	4.23	7.05
Fraxinus nigra Marsh.	.18	.25	2.22	4.23	6.45
Acer rubrum L.	.28	.17	3.43	2.82	6.25

APPENDIX IV

SAMPLING SUMMARIES OF WOODY VEGETATION FOR THE SKUNK CREEK BASIN

Table 1. Density and Frequency of Trees Sampled in Northern Hardwoods (Aspen-Birch Type) Forest (N=792)

Species	Density	Relative Density	Frequency	Relative Frequency	Importance Value
Populus tremuloides Michx.	96.59	31.69	56.06	24.45	28.62
Abies balsamea (L.) Mill.	53.10	17.42	37.88	16.52	16.27
Betula papyrifera Marsh.	45.02	14.77	38.89	16.96	15.90
Fraxinus nigra Marsh.	38.48	12.63	25.25	11.01	11.50
Acer rubrum L.	19.24	6.31	17.68	7.71	7.01

(Density = 304.8 trees/hectare; mean diameter = 19.7 cm; mean Point-to-Tree Distance = 5.7m)

Table 2. Density and Frequency of Trees Sampled in Northern Hardwoods (Maple-Basswood Type) Forest (N=100)

Species	Density	Relative Density	Frequency	Relative Frequency	Importance Value
Acer saccharum Marsh.	146.63	33.00	64.00	26.67	32.53
Betula papyrifera Marsh.	57.76	13.00	40.00	16.67	13.89
Populus tremuloides Michx.	48.88	11.00	24.00	10.00	11.34
Tilia americana L.	44.43	10.00	32.00	13.33	10.57
Abies balsamea (L.) Mill.	62.21	14.00	20.00	8.33	9.78
Acer rubrum L.	35.55	8.00	24.00	10.00	7.31
Ulmus americana L.	8.89	2.00	8.00	3.33	5.06

(Density = 444.3 trees/hectare; mean diameter = 20.8 cm; mean Point-to-Tree Distance = 4.7m)

Table 3. Density and Frequency of Trees Sampled in Conifer Type Forests (N=60)

Species	Density	Relative Density	Frequency	Relative Frequency	Importance Value
Picea mariana (Mill.) BSP.	363.19	56.67	93.33	40.00	49.72
Populus tremuloides Michx.	149.55	23.33	73.33	31.43	26.47
Picea glauca (Moench) Voss.	64.09	10.00	33.33	14.29	12.27
Abies balsamea (L.) Mill.	53.41	8.33	26.67	11.43	9.76
Pinus strobus L.	10.68	1.67	6.67	2.86	1.78

(Density = 640.9 trees/hectare; mean diameter = 15.9 cm; mean Point-to-Tree distance = 3.9m)

Table 4. Density and Frequency of Shrubs Sampled Northern Hardwoods (Aspen-Birch Type) Forest (N=40)

Species	Density	Relative Density	Frequency	Relative Frequency	Importance Value
Crateagus sp.	4.14	29.87	.65	11.21	41.08
Amelanchier sp.	1.52	10.93	.40	6.90	17.83
Cornus sp.	1.22	8.80	.50	8.62	17.42
Prunus pensylvania L.f.	.94	6.75	.50	8.62	15.37
Alnus rugosa (DuRoi) Spreng.	.74	5.30	.23	3.88	9.18
Dirca palustris L.	.67	4.80	.23	3.88	8.68
Acer saccharum Marsh.	.42	3.03	.33	5.60	8.63
Betula papyrifera Marsh.	.31	2.24	.33	5.60	7.84
Corylus cornuta Marsh.	.66	4.77	.18	3.02	7.78
Rosa sp.	.52	3.72	.23	3.88	7.60

Table 5. Density and Frequency of Shrubs Sampled in Northern Hardwoods (Maple-Basswood Type) Forest (N=5)

Species	Density	Relative Density	Frequency	Relative Frequency	Importance Value
Alnus rugosa (DuRoi)Spreng.	3.04	29.23	1.00	19.23	48.46
Acer spicatum Lam.	1.80	17.31	.80	15.38	32.69
Prunus pensylvania L.f.	2.16	20.77	.60	11.54	32.31
Crateagus sp.	1.52	14.62	.60	11.54	26.15
Acer saccharum Marsh.	1.00	9.62	.40	7.69	17.31
Acer rubrum L.	.28	2.69	.60	11.54	14.23
Picea glauca (Moench) Voss.	.20	1.92	.20	3.85	5.77
Cornus sp.	.12	1.15	.20	3.85	5.00
Ledum sp.	.12	1.15	.20	3.85	5.00

Table 6. Density and Frequency of Shrubs Sampled in Coniferous Forests (N=3)

Species	Density	Relative Density	Frequency	Relative Frequency	Importance Value
Lonicera canadensis Marsh.	14.27	45.24	1.00	14.29	59.53
Viburnum lentago L.	5.60	17.76	.67	9.52	27.28
Ostrya virginiana (Mill.) K. Koch	5.20	16.49	.67	9.52	26.01
Salix sp.	1.40	4.44	1.00	14.29	18.73
Prunus pensylvania L.f.	1.47	4.65	.67	9.52	14.18
Sorbus decora (Sarg.) C.K. Schneid	.93	2.96	.67	9.52	12.48
Betula papyrifera Marsh.	.67	2.11	.33	4.76	6.88
Amelanchier sp.	.47	1.48	.33	4.76	6.24
Ledum sp.	.40	1.28	.33	4.76	6.03
Pinus resinosa Ait.	.13	.42	.33	4.76	5.18

APPENDIX V

SUMMARY OF MAJOR GROUND COVER SPECIES BY STAND

Little Balsam Watershed

(Tables 1-6)

Skunk Creek Watershed

(Tables 7-11)

B = Phytomass (gms/m^2)

RB = Relative Phytomass

F = Frequency

RF = Relative Frequency

IP = Importance Percentages

Table 1. Summary of Seasonal Herbaceous Quadrat Sampling in Aspen Hardwoods, Little Balsam.

Species	Vernal (n = 7)					Aestival (n = 8)					Autumnal (n = 5)				
	B	RB	F	RF	IP	B	RB	F	RF	IP	B	RB	F	RF	IP
Aster macrophyllus	18.4	44.7	.71	9.6	54.4	19.7	29.9	.63	7.6	37.5	9.6	21.6	.40	7.1	28.7
Carex sp.	6.3	15.4	.71	9.6	25.0	9.5	14.4	.75	9.1	23.5	5.9	13.3	.80	14.3	27.6
Fragaria virginiana	1.9	4.7	.57	7.7	12.4	3.5	5.4	.63	7.6	13.0	1.2	2.6	.40	7.1	9.8
Rubus pubescens	2.4	5.8	.43	5.8	11.6										
Maianthemum canadense	1.7	4.1	.43	5.8	9.8										
Aralia nudicaulis						5.9	9.0	.25	3.0	12.0					
Sanicula marilandica						2.3	3.4	.50	6.1	9.4					
Rhus radicans						4.8	7.4	.13	1.5	8.9					
Vaccinium sp.											7.8	17.7	.20	3.6	21.3
Geum laciniatum											3.4	7.7	.20	3.6	11.3

Table 2. Summary of Seasonal Herbaceous Quadrat Sampling in Northern Hardwoods (Aspen/Birch), Little Balsam.

	Vernal (n = 5)					Aestinal (n = 5)					Autumnal (n = 5)				
Species	B	RB	F	RF	IP	B	RB	F	RF	IP	B	RB	F	RF	IP
Aster macrophyllus	13.2	35.0	.80	8.1	43.2	4.6	7.9	.57	7.8	15.7	15.4	26.5	1.0	17.2	43.8
Pteridium aguilinum	5.1	13.5	.40	4.1	17.6	8.0	13.8	.14	2.0	15.8					
Maianthemum canadensis	1.0	2.8	.60	6.1	8.9										
Carex pensylvanica	1.6	4.3	.40	4.1	8.4						7.7	13.2	.60	10.3	23.6
Clintonia borealis	1.5	4.0	.40	4.1	8.0										
Bromus sp.	2.2	5.8	.20	2.0	7.8										
Viola sp.	0.6	1.6	.60	6.1	7.7										
Aralia nudicaulis						7.2	12.4	.71	9.8	22.2					
Athyrium sp.						8.9	15.3	.14	2.0	17.3					
Glyceria striata						5.1	8.8	.14	2.0	10.7					
Diervilla lonicera						3.1	5.3	.29	3.9	9.3					
Apocynum androesaemifolium						3.4	5.7	.14	2.0	7.7					
Luzula acuminata											9.8	16.9	.20	3.4	20.3
Juncus sp.											7.5	13.0	.20	3.4	16.5

Table 3. Summary of Seasonal Herbaceous Quadrat Sampling in Northern Hardwoods (Oak/Maple), Little Balsam

Species	Vernal (n = 6)					Aestival (n = 5)					Autumnal (n = 7)				
	B	RB	F	RF	IP	B	RB	F	RF	IP	B	RB	F	RF	IP
Maianthemum canadense	1.4	13.3	.83	13.5	26.9	2.1	7.6	1.00	16.1	23.7	9.6	32.3	.71	15.1	47.5
Pteridium aguilinum	2.8	20.1	.33	5.4	25.4	5.8	20.9	.20	3.2	24.1					
Clintonia borealis	1.9	13.7	.50	8.1	21.8										
Aster macrophyllus	1.2	8.4	.67	10.8	19.3	10.3	36.9	1.00	16.1	53.0					
Carex sp.	1.6	11.5	.33	5.4	16.9						3.6	12.1	.14	3.0	15.1
Acer rubrum(seedlings)						1.2	4.3	.80	12.9	17.0					
Diervilla lonicera[a]											3.5	11.8	.57	12.1	24.0
Lycopodium complanatum											3.6	12.1	.14	3.0	15.2
L. obscurum											2.6	8.7	.29	6.1	14.7

[a]partially woody.

Table 4. Summary of Herbaceous Quadrat Sampling in Ravine Forests, Little Balsam.

	= Vernal (n = 7)					Aestival (n = 4)					Autumnal (n = 7)				
Species	B	RB	F	RF	IP	B	RB	F	RF	IP	B	RB	F	RF	IP
Aster macrophyllus	13.9	32.3	.71	11.6	43.9	6.5	6.1	1.00	14.3	20.4	13.3	21.0	.86	15.8	36.8
Carex sp.	5.4	12.7	.43	7.0	19.7	7.2	6.7	.75	10.7	17.4	7.5	11.8	.43	7.9	19.7
Equisetum hyemale	6.7	15.5	.14	2.3	17.9	76.8	72.3	.25	3.6	75.9	29.6	46.8	.29	5.3	52.1
Carex pensylvanica	4.8	11.1	.29	4.7	15.8										
Rubus pubescens	3.6	8.3	.14	2.3	10.7										
Aralia nudicaulis						2.9	2.8	.75	10.7	13.5					
Pyrola rotundifolia											3.5	5.6	.57	10.5	16.1

Table 5. Summary of Wetland Hardwood Forests, Little Balsam.

	Vernal (n = 2)					Aestival (n = 8)					Autumnal (n = 2)				
Species	B	RB	F	RF	IP	B	RB	F	RF	IP	B	RB	F	RF	IP
Equisetum hyemale	503.1	92.9	.50	10	102.9	72.1	67.2	.67	10	77.2	220	82.3	.5	7.7	90.5
Carex sp.	14.1	2.6	.50	10	12.6	2.5	2.3	.67	10	12.3	8.4	3.2	.50	7.7	10.9
Rubus parviflorus	12.9	2.4	.50	10	12.4										
Saxafraga pensylvanica	4.4	.82	.50	10	10.8										
Equisetum arvense						11.5	10.7	.33	5	15.7					
Uvularia sessilifolia						4.8	4.5	.33	5	9.5					
Matteuccia struthiopteris											29.3	11.0	.50	7.7	18.7

Table 6. Summary of Herbaceous Quadrat Sampling in Agricultural Fields, Little Balsam.

	Vernal (n = 5)					Aestival (n = 6)					Autumnal (n = 6)				
Species	B	BR	F	RF	IP	B	RB	F	RF	IP	B	RB	F	RF	IP
Poa sp.	12.6	19.2	.60	7.1	26.3						4.0	3.0	.33	3.2	6.2
Fragaria virginiana	8.0	12.2	.60	7.1	19.4	18.1	9.4	.83	7.8	17.2	11.2	8.3	1.00	9.5	17.9
Bromus sp.	8.0	12.1	.60	7.1	19.3										
Aster sp.	8.0	12.1	.40	4.8	16.9						18.9	14.0	.67	6.3	20.5
Solidago sp.[a]	3.7	5.6	.80	9.5	15.1	13.9	7.2	.50	4.7	11.9	38.0	28.3	.67	6.3	35.5
Agropyron repens	4.8	7.3	.40	4.8	12.1	15.5	8.0	.50	4.7	12.7					
Agrostis stolonifera						26.2	13.6	.50	4.7	18.3					
Phleum pratense						18.6	9.7	.50	4.7	14.4	14.9	11.1	.67	6.3	17.5
Solidago canadensis						21.2	11.0	.17	1.6	12.6					
Pteridium aquilinum						20.7	10.7	.17	1.6	12.3					
Carex sp.											9.4	7.0	.67	6.3	13.4
Aster simplex															

[a] including *S. canadensis* in vernal sample only.

Table 7. Summary of Seasonal Herbaceous Quadrat Sampling in Aspen Hardwoods, Skunk Creek.

Species	Vernal (n = 2)					Aestival (n = 2)					Autumnal[a] (n = 2)				
	B	RB	F	RF	IP	B	RB	F	RF	IP	B	RB	F	RF	IP
Carex sp.	5.5	19.1	1.00	10.5	29.6	4.2	5.6	1.00	10.5	20.3	5.6	14.6	.50	20.0	34.6
Clintonia borealis	6.2	21.2	.50	5.3	26.5										
Aster macrophyllus	5.8	19.9	.50	5.3	25.2	42.0	55.6	1.00	10.5	66.2					
Mulhenbergia sp.	4.8	16.4	.50	5.3	21.6										
Tralictrum dioicum	1.2	4.0	1.00	10.5	14.5										
Fragaria virginiana	1.0	3.3	.50	5.3	8.6	5.5	7.3	1.00	10.5	17.9	1.0	2.6	.50	20.0	22.6
Sanicula marilandica						6.4	8.5	1.00	10.5	19.1					
Cinna latifolia											31.4	81.5	.50	20.0	101.5

[a] atypical sample with low species number.

Table 8. Summary of Seasonal Herbaceous Quadrat Sampling in Northern Hardwoods (Aspen/Birch), Skunk Creek.

	Vernal (n = 5)					Aestival (n = 13)					Autumnal (n = 12)				
Species	B	RB	F	RF	IP	B	RB	F	RF	IP	B	RB	F	RF	IP
Aster macrophyllus	9.3	23.4	.78	8.4	31.8	23.6	43.1	.77	8.9	52.1	10.1	20.1	.58	9.3	29.4
Pteridium aguilinum	5.3	13.3	.11	1.2	14.5	6.7	12.2	.15	1.8	14.0					
Carex sp.	3.5	8.8	.44	4.8	13.7	2.0	3.7	.54	6.3	9.9	9.5	22.6	.58	10.6	29.6
Rubus pubescens	2.1	5.4	.56	6.0	11.4	2.6	4.8	.61	7.1	11.9					
Asarum canadensis	3.9	9.8	.11	1.2	11.0										
Fragaria virginiana	2.0	5.1	.44	4.8	9.9	1.5	2.7	.62	7.1	9.9	3.3	6.6	.33	5.3	11.9
Athyrium sp.	2.5	6.4	.11	1.2	7.6										
Maianthemum canadense	0.2	0.6	.56	6.0	6.6	1.4	2.6	.77	8.9	11.6					
Sanicula marilandica						2.4	4.3	.38	4.5	8.8					
Vaccinium sp.											8.7	17.3	.10	1.3	18.7
Luzula sp.											2.9	5.8	.33	5.3	11.1

Table 9. Summary of Seasonal Herbaceous Quadrat Sampling in Ravine Forests, Skunk Creek.

Species	Vernal (n = 5)					Aestival (n = 5)					Autumnal (n = 5)				
	B	RB	F	RF	IP	B	RB	F	RF	IP	B	RF	F	RF	IP
Carex sp.	12.0	49.4	1.00	13.9	63.3	16.6	23.8	1.00	10.0	36.3	9.4	28.5	.80	11.4	39.9
Aster macrophyllus	3.8	15.8	.40	5.5	21.4	15.5	22.3	.80	8.3	30.6	11.9	36.3	.80	11.4	47.7
Fragaria virginiana	.61	2.5	.60	8.3	10.8	1.5	2.1	.60	6.3	8.4	1.0	32.9	.60	8.6	11.5
Rubus pubescens	.96	3.9	.40	5.5	9.5	0.4	0.6	.60	6.3	6.8	1.0	2.9	.40	5.7	8.6
Mitella nuda	.50	2.0	.40	5.5	7.6										
Equisetum arvense						2.6	3.8	.40	4.2	7.9					
Lonicera sp.[a]						17.1	24.5	.20	2.1	26.5					

[a] partially woody, ground layer.

Table 10. Summary of Seasonal Herbaceous Quadrat Sampling in Hardwood Wetlands, Skunk Creek.

Species	Vernal (n = 6)					Aestival (n = 6)					Autumnal (n = 6)				
	B	RB	F	RF	IP	B	RB	F	RF	IP	B	RB	F	RF	IP
Laportea canadensis	11.9	26.2	.33	3.9	30.2	11.2	19.2	.33	3.5	22.7					
Carex sp.	5.7	12.5	.83	9.8	22.3	12.3	14.2	.83	10.6	29.2	3.8	11.9	.67	11.8	23.6
Asarum canadensis	4.7	10.3	.33	3.9	14.2						3.0	9.5	.17	2.9	12.4
Fragaria virginiana	2.4	5.3	.50	5.9	11.2						1.4	4.6	.50	8.8	13.4
Aster macrophyllus	3.4	7.5	.17	2.0	9.5	4.3	3.7	.17	1.8	9.2	4.3	13.5	.33	5.9	19.4
Viola sp.	3.4	7.4	.17	2.0	9.4	2.7	4.6	.50	5.3	9.9					
Athyrium sp.	3.3	7.4	.17	2.0	9.3										
Rubus pubescens						2.7	4.6	.50	5.3	9.9					
Solidago sp.						6.5	11.2	.17	1.8	13.0					
Glyceria striata						2.3	4.0	.33	3.5	7.5					
Elymus virginicus											8.3	26.3	.17	2.9	29.3
Aster sp.											3.5	11.2	.33	5.9	17.1

Table 11. Summary of Seasonal Herbaceous Quadrat Sampling in Agricultural Fields, Skunk Creek.

	Vernal (n = 6)					Aestival (n = 8)					Autumnal (n = 7)				
Species	B	RB	F	RF	IP	B	RB	F	RF	IP	B	RB	F	RF	IP
Poa sp.	13.5	16.6	.67	6.8	24.0										
Bromus sp.	7.9	9.6	.67	6.8	16.4	26.6	16.1	.14	1.7	17.8	6.7	6.4	.28	3.6	10.1
Agrostis sp.	6.9	8.5	.50	5.1	13.6	20.4	12.3	.28	3.4	15.8					
Achillea millefolium	2.6	3.2	.83	8.5	11.7	10.1	6.1	.57	6.8	12.9					
Luzula acuminata	6.8	8.4	.17	1.7	10.1										
Fragaria virginiana	2.7	3.3	.67	6.8	10.1	17.9	10.8	.71	8.5	19.3	8.7	8.3	.86	10.9	19.2
Carex sp.	3.9	4.8	.33	3.4	8.2						5.7	5.5	.29	3.6	9.1
Phleum pratense						15.2	9.2	.57	6.8	16.0	33.3	31.9	.57	7.3	39.1
Aster ciliolatus						8.6	5.2	.43	5.1	10.3					
Solidago sp.											7.9	7.6	.14	1.8	9.4

APPENDIX VI

VEGETATION COVER MAPS

Little Balsam Watershed

Skunk Creek Watershed

Forest Types

I. Aspen Hardwoods

II. Northern Hardwoods

A. Aspen/Birch Dominant

B. Oak/Maple Dominant

C. Maple/Basswood Dominant

III. Coniferous

IV. Ravine Forests (Birch/Fir)

V. Plantations

Wetlands

VI. Hardwood Swamp

VII. Conifer Swamp (Cedar/Ash)

VIII. Bog

IX. Wet Shrubland

Field

X. Abandoned Fields

A. Herbaceous

B. Shrubby

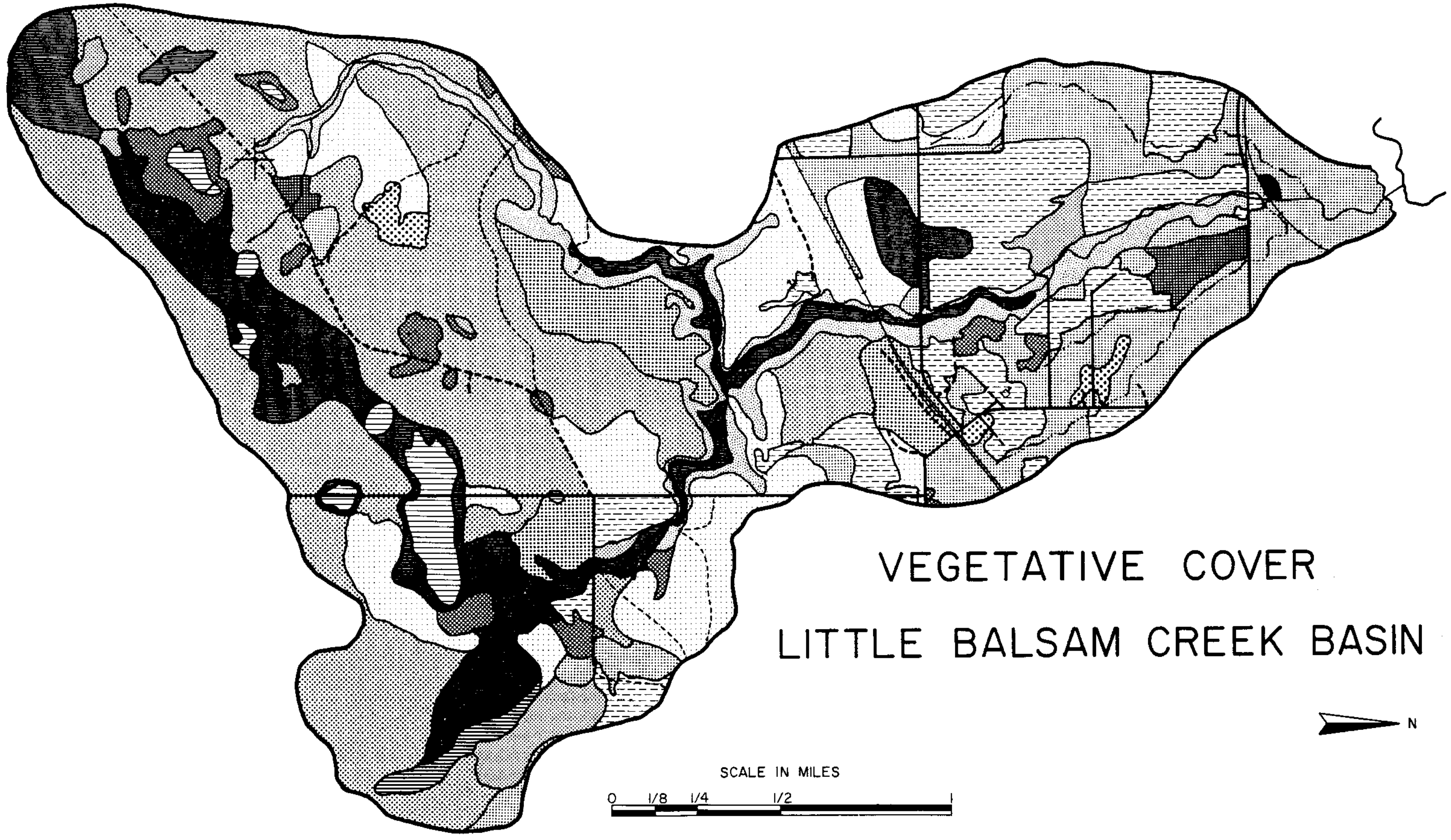
C. Wet

XI. Agricultural Fields

A. Field

B. Pasture

XII. Construction Zone


VEGETATIVE COVER
LITTLE BALSAM CREEK BASIN
N
SCALE IN MILES
0 1/8 1/4 1/2 1

Woodlands

I. Aspen Hardwoods

II. Northern Hardwoods

A. Aspen/Birch Dominant

B. Oak/Maple Dominant

C. Maple/Basswood Dominant

III. Conifer

IV. Ravine Forest

V. Plantations

Wetlands

VI. Hardwood Swamp

VII. Conifer Swamp

VIII. Bog

IX. Wet Shrubland

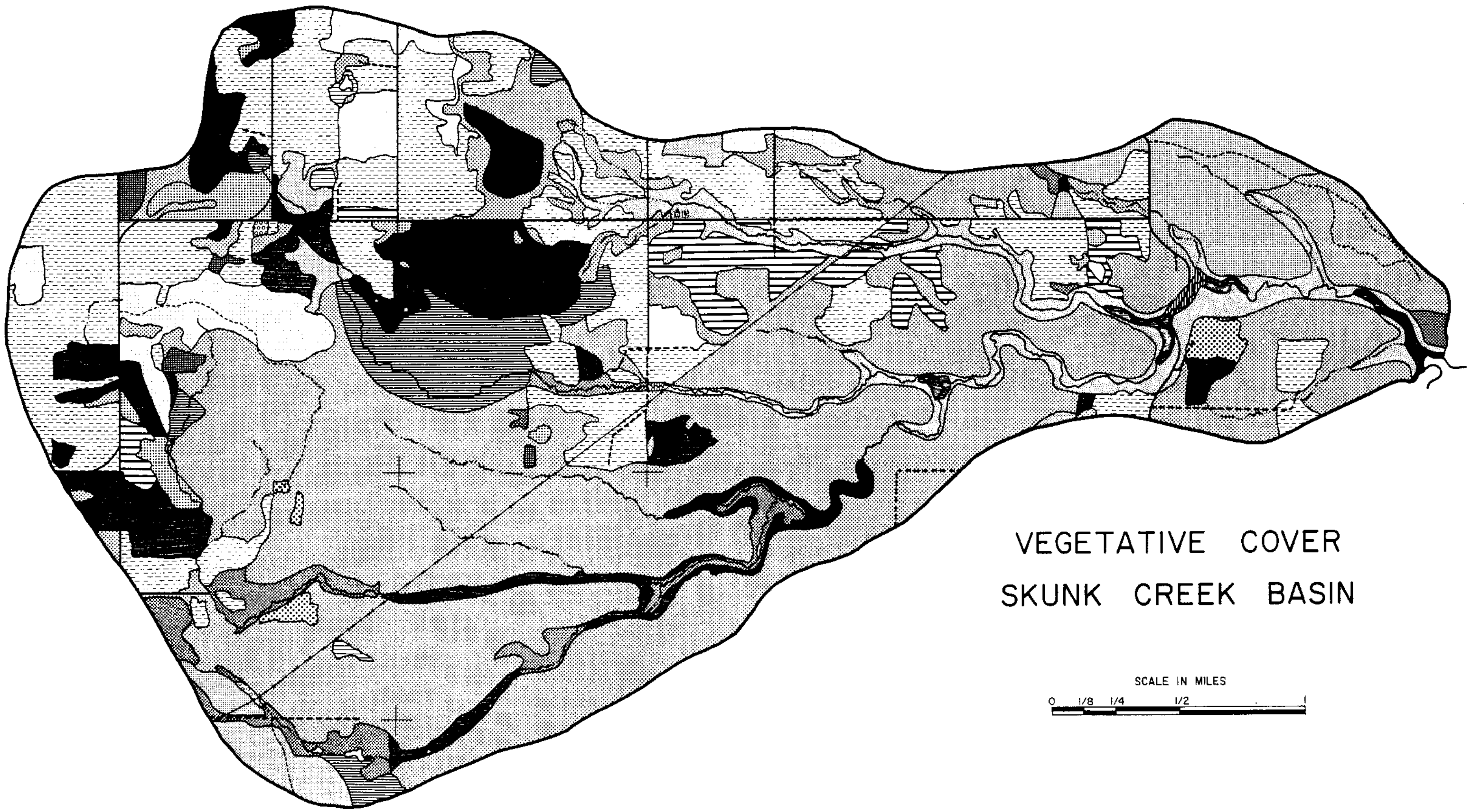
Fields

X. Abandoned Fields

A. Herbaceous

B. Shrubby

XI. Agricultural Fields



VEGETATIVE COVER
SKUNK CREEK BASIN

EFFECT OF VEGETATION COVER ON SOIL WATER CONTENT OF RED CLAY SOILS AND EROSION CONTROL

Lawrence A. Kapustka and Rudy G. Koch*

This project sought to determine the relationships of the various vegetational covers found in the red clay area to soil water content and to identify the role of these plant-soil moisture relationships in red clay erosion.

METHODS

Site Location and Instrumentation

Field sites were situated in the Little Balsam Creek Basin. The sites for the individual plots were selected to maximize the types of vegetational cover available in a relatively small area, thus minimizing expenditures in equipment and field monitoring time, as well as to provide better control conditions for soil and slope.

A central weather station located on the Johnson property (T46N, R15W, S3) was established prior to the spring thaw, 1976. The station was serviced weekly from 5 April 1976 through 27 September 1976, and 4 April 1977 through 5 November 1977. Instrumentation in the weather unit included: pyranograph, hydrothermograph, and total precipitation. Weather monitoring summaries were developed from respective recording chart readings at 2 h intervals.

Nine sites were identified within a 200 m radius of the weather station to represent the following vegetation covers: aspen, birch, fir, maple, pine, grazed pasture, bare of vegetative cover, and abandoned (agriculture) field. The last cover type was represented by both a shallow and a deep enclosure. The plots (1.0 m x 2.0 m), were enclosed by a perimeter of glavanized, corrugated roofing metal buried to a depth of approximately 10 cm. The one "deep enclosure" (abandoned field) had the metal buried to a depth of one meter to provide a grassy area isolated from the potential influence of roots of neighboring trees.

Five gypsum conductivity blocks were mounted in 1.3 cm (1/2 in.) diameter plastic water pipe with the sensors exposed at 5, 15, 30, 60 and 100 cm below the burial line. Three of these probes were installed in each of the nine

*Project Specialist, C.L.S.E.S. and Assoc. Prof., Biolgoy; UW-Superior

enclosed plots. Auger holes (5 cm diam.) were drilled and the probe assembly was placed at the desired depth with disturbance to the soil and vegetation held to a minimum.

Five sets of thermistor probes were assembled and installed in the study area in a similar manner.

Soil moisture and soil temperature were monitored weekly with a Beckman Model SMB-1 Soil Moisture Bridge and an Atkins electronic thermometer respectively. Water holding capacity of the red clay was determined following the procedures described by Hilgard (1).

Permanent wilting point was determined with young sunflower plants (2nd - 3rd set of leaves) following the methods of Briggs and Shantz (2).

Throughfall-Stemflow

Eighteen trees representing *Populus tremuloides*, *Betula papyrifera*, *Acer rubra*, *Quercus borealis*, *Abies balsamea*, *Picea glauca*, and *Piuus strobus* were prepared for monitoring stemflow (SF) and throughfall (TF) during 1976. In April 1977, 10 aspen and 10 birch representing a wide range of tree sizes were equipped for monitoring. Rain gauges were placed in a fixed pattern under the canopy to detect the amount of TF which was then compared to the amounts of incident precipitation measured in gauges in the open (3). Three gauges were placed along each of the cardinal directions (with the bole of the tree being the origin) to collect TF of the inner canopy, middle canopy, and outer canopy. A polyurethane collar was molded to the trunk of each tree to enable collection of SF water following procedures described by Likens and Eaton (4). During the 2 years of monitoring 35-50 rain periods (depending on the time of installation for the various specimens) were measured for SF and TF.

Plant Growth on Amended Soils

Seeds of species used to revegetate erosion zones of red clay soils in Wisconsin and Minnesota were obtained from Trico Services, Inc., 2102 W. Michigan Street, Duluth, Minnesota 55806. Five replicates of 50 seeds each were placed on moist filter paper and incubated at 25 ± 3°C. Germinated seeds (those with radicle extension past the seed coat) were removed and tallied. Germination value was calculated after Czabatior (5).

Initial measures of soil pH and organic carbon content indicated a possible requirement for soil amendments to achieve optimum plant growth on exposed sites. Clay soil, for use in controlled environment studies, was collected from an exposed bank near Little Balsam Creek (T46N, R15W, S3). The soil was air dried, pulverized, and sifted through a 2.0 mm mesh screen to remove gravel and unbroken aggregates of clay.

The pH of the soil was 8.1 (5 water: 1 soil/v/w) and the organic carbon content (Wakley-Black Value; 6) was 0.2%.

Lots of soil were amended with $CaSO_4$ to achieve a final pH = 7.3, with CaO to achieve pH = 8.6. Seeds of *Festuca elatior*, *F. rubra*, *Lolium perenne* and *Bromus inermis* were planted in glass cylinders 4 cm diameter x 10 cm in height and equipped with a siphon watering system that maintained the soil moisture content at 90% or more of field capacity. Five to 6 seedlings were maintained in each of 7 jars for each species-pH treatment. Plants were exposed to 16 hour light: 8 hour dark periods with corresponding temperatures of 25.5° and 15.5° C respectively, and continuous 65-70% relative humidity.

The water supply was removed 3 weeks after plantings. Measures of leaf water potential (Wescor C-52 psychrometer), xylem water potential (PMS pressure bomb), fresh and oven dry (80° C, 48 h) weights were obtained the day the water was withdrawn and on subsequent days 1, 2, 3, 4, 7 and 8. The soil moisture content was determined gravimetrically for each jar at the time of harvest.

Additional experiments to determine the influence of soil organic carbon content on growth were conducted with the same species. Lots of soil were amended to achieve 2% and 4% carbon with either peat moss or pulverized aspen leaves as the source of carbon. Half of the treatments received Hoagland's nutrient solution at a rate equivalent to 50 kg $N \cdot ha^{-1}$. Twenty seedlings were maintained per jar for 5 weeks. Weekly measures of height were recorded. After 5 weeks, the plants were harvested to obtain fresh and dry weights.

RESULTS

Weather

Summaries of ambient temperature, relative humidity, solar insolation, wind and precipitation for the 1976-77 field seasons are presented in Appendix I.

Soil Temperature

Comparisons of soil temperatures of the 5 vegetative cover types reveal significant differences among all sites for virtually the entire monitoring period. In general the sites in order of decreasing temperatures were: pasture, ungrazed grass, birch, maple, pine. These differences are seen most clearly at the greater soil depth. Some of these differences, particularly the pine and maple sites, are possibly a result of slope position and not solely a characteristic of the vegetation and the associated ground cover. (See Appendix II for graphs of 1976 soil temperature profiles).

1977 data is not presented as it followed a pattern similar to 1976 data).

Soil Water Holding Properties

The water holding capacity of three soil samples expressed as percentage dry weight were 50.46, 55.87, and 56.10%.

The mean permanent wilting point was determined from 6 replicates to be at 11.8% soil moisture with the S.E. = 0.3%.

Soil Moisture

The unusually dry summer of 1976 provided excellent conditions for monitoring the effects of vegetation cover types of soil moisture. Depletion of soil moisture was considerable in all plots as precipitation declined. The most effective cover types with respect to the depletion of soil moisture were grazed pasture, abandoned field with predominant grass cover ans aspen. Much less effective were fir, pine, maple, and bare ground. (See Appendix III for graphs of 1976 soil moisture profiles.)

Following light rains the surface soils (top 5 cm) with less cover (bare soil and grazed pasture) recharged more extensively than soils with more cover, reflecting the significance of rainfall interception by vegetation. With larger rains the bare soils were less efficient in capturing the precipitation than the more vegetated soils. The vegetated soils tend to have a more porous structure resulting from a higher organic carbon content, from root penetration and subterranean animal activity which promotes percolation. In the more compacted bare soils the surface is readily saturated and excess moisture is lost as surface runoff.

The summer of 1977 was wetter than normal with numerous small rains occurring throughout the months of April through June and mid July through October. Except for a brief period in early July the soils in all plots remained relatively saturated (Ψ soil = -1.5 to -4.0 atmos.) throughout the 1 m profile. The surface soils (upper 15 cm) began to dry down in the same pattern as observed in 1976.

Stemflow-Throughfall

The marked difference in precipitation between 1976 and 1977 also had an influence on the pattern of SF and TF observed during the two years. In 1976, the amount of SF for any given specimen was not correlated with the amount of incident precipitation. The 1977 data for SF shows a significant correlation. The patterns of TF for 1976 were correlated strongly with incident precipitation wheras the patterns of TF for 1977 were less rigorously defined. The apparent explanation for these differences in patterns rests with the extent of wetness of the bark and leaf surfaces. In 1976 the interval between rain periods generally allowed for considerable drying of the plant surfaces. Consequently some water was sorbed by the tree reducing SF and TF tended to be initialed with the slightest shower.

Even with these differences, general patterns were discernable. For example, mid to large size birch with its curled bark tend to have small amounts of stemflow compared to other deciduous species of similar size. Trees with lateral branches angled upward have larger volumes of stemflow than trees with spreading branches. Although the volume of stemflow often exceeds 20 l for rains of 1 cm or more, this redistribution represents a very small percentage of the incoming rain. If stemflow is divided by the projected area of the canopy the stemflow typically is <1% of the incident precipitation.

Significant differences in TF were apparent among the different positions of the canopy (inner, middle, outer) for many specimens. Also major differences exist among the species and sizes of trees (Tables 1, 2). Generalized features of TF (Figures 1 - 3) are obtained from the linear regression analysis of TF and incident rainfall.

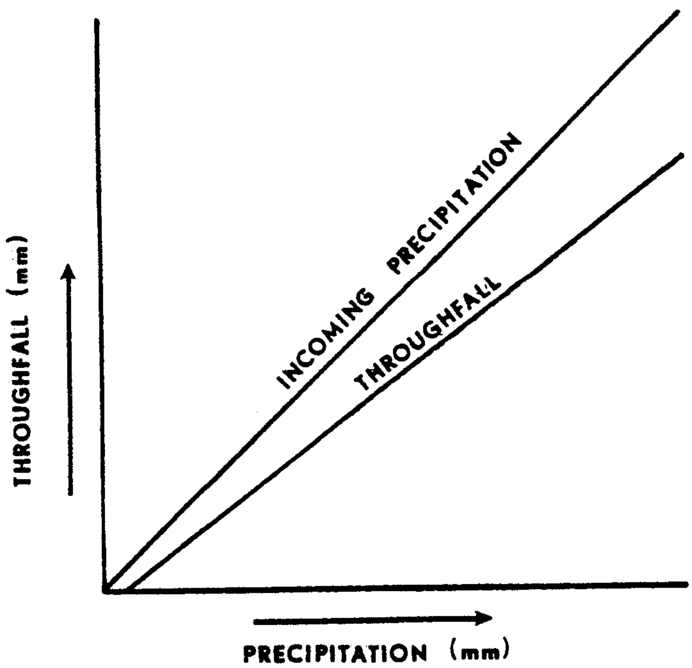


Figure 1. Relationship Between Precipitation (cm) and Throughfall (% of Incoming Precipitation).

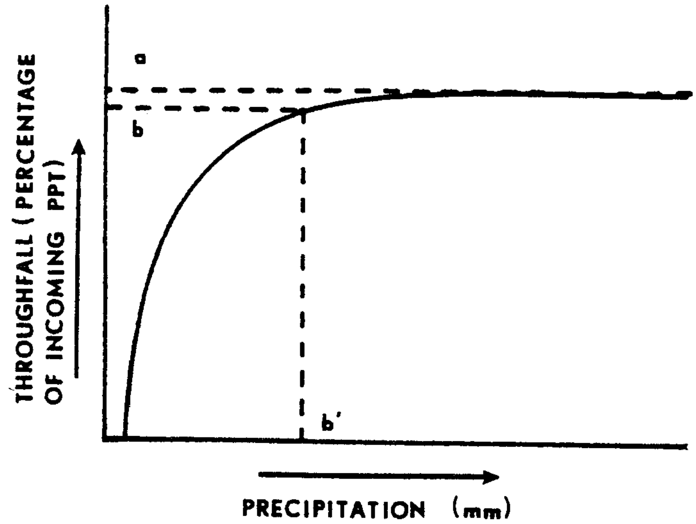


Figure 2. Relationship Between Precipitation (cm) and Throughfall (cm).

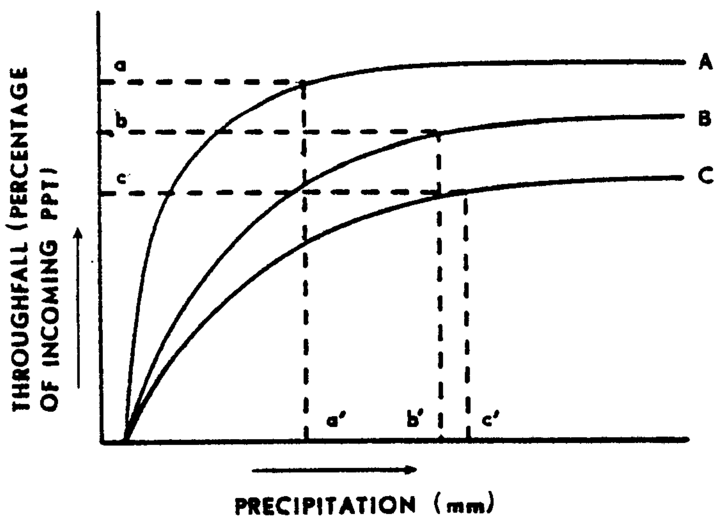


Figure 3. Throughfall Patterns for Three Canopy Types. (A. Open canopy type such as aspen; B. Moderately dense canopy type such as oak; C. Dense canopy type such as spruce.)

Table 1. Summary of physical features of trees used for SF and TF measures.

Tree ID #	Type	DBH (cm)	Total[1] Height (m)	Canopy Height (m)	Canopy Area (m^2)	Canopy Density[2] I	M	O	Mean	Bark[3] Features
1	Aspen	20.2	11.6	8.9	14.39	50	60	50	53	MF
2	Aspen	30.7	14.2	12.2	22.63	40	55	68	54	HF
3	Aspen	28.6	12.8	11.6	19.60	59	54	46	53	HF
4	Aspen	9.3	9.6	8.9	2.61	57	54	53	55	MF
5	Aspen	8.5	7.5	6.3	3.62	48	50	52	50	MF
6	Aspen	18.5	14.2	13.1	15.72	41	51	42	45	HF
7	Aspen	17.6	13.2	12.0	8.27	32	36	37	35	HF
8	Aspen	17.8	10.4	9.4	14.99	53	51	47	51	HF
9	Aspen	7.5	9.8	8.8	2.46	81	59	57	66	LF
10	Aspen	12.3	13.6	12.6	4.32	48	50	57	52	MF
11	Aspen	9.9	12.2	11.2	5.20	60	60	54	58	MF
12	Aspen	5.4	6.9	5.5	3.19	57	44	56	52	MF
13	Aspen	27.8	21.0	19.1	24.00	65	68	52	61	MF
14	Birch	16.0	9.0	7.7	16.88	51	47	50	49	SC
15	Birch	29.4	16.5	12.4	24.76	32	40	48	40	EC
16	Birch	22.8	15.7	13.9	48.84	49	60	37	50	MC
17	Birch	7.8	5.9	5.1	6.51	64	70	80	72	SC
18	Birch	6.0	4.4	3.9	6.81	63	50	60	58	S
19	Birch	9.6	6.9	6.7	7.40	51	50	57	52	MC
20	Birch	9.8	8.9	7.6	6.54	80	86	82	83	SC
21	Birch	11.8	8.6	7.9	10.17	41	50	50	47	SC
22	Birch	25.3	8.1	5.4	24.29	57	68	67	64	EC
23	Birch	27.1	13.5	11.4	29.34	47	64	50	54	HF
24	Birch	16.8	14.5	11.5	9.57	52	44	44	47	HF
25	Birch	16.6	8.1	7.3	11.41	62	77	80	73	MF
26	Birch	16.1	8.3	7.3	17.06	65	76	78	73	MF
27	Oak	26.7	14.1	16.9	52.41	39	28	34	34	MF
28	Oak	30.4	13.4	11.2	43.48	36	49	45	43	MF
29	Maple	23.2	13.5	10.7	17.04	28	45	31	34	MF
30	Maple	25.5	9.5	8.2	36.81	43	56	50	49	MF
31	Maple	28.5	10.9	8.3	28.17	47	45	40	44	MF
32	Spruce	14.8	5.6	4.2	12.01	70	69	60	65	MF
33	Spruce	25.0	12.8	12.6	19.44	47	50	59	51	MF
34	Fir	10.7	7.5	7.5	6.07	13	19	23	18	MF
35	Fir	16.6	12.3	12.0	7.75	27	27	22	26	MF
36	Fir	13.9	8.5	8.2	11.33	19	34	17	25	MF
37	Pine	41.3	15.0	11.4	15.20	33	49	52	45	HF
38	Pine	41.2	16.2	12.0	35.80	27	27	40	31	HF

[1]Measured by triangulation

[2]Inner, middle and outer, density determined from the mean light intensity penetrating to the forest floor at 4 locations (corresponding to the position of rain gauges) expressed as a percentage of light in an open area all

(continued)

measures were taken on clear days between 11:00 a.m. and 1:00 p.m. CST with a Photovolt Model 200 Photorectery.

[3]S = smooth, LF = lightly furrowed, MF = moderately furrowed, HF = heavely furrowed, SC = smooth to slightly curled, MC = moderately curled, EC - extensively curled.

TABLE 2. Summary of Regression Analysis for 1976 and 1977 Data. (I = Inner Ring, M = Middle ring, O = Outer ring, T = Total and TF = A + B (PPT).

		r^2	A	B
Aspen 1	I	0.835	-0.195	0.917
	M	0.831	-0.180	0.932
	O	0.831	-0.180	0.932
	T	0.838	-0.185	0.915
Aspen 2	I	0.848	-0.116	0.871
	M	0.872	-0.112	0.922
	O	0.872	-0.112	0.922
	T	0.873	-0.118	0.903
Aspen 3	I	0.847	-0.199	0.910
	M	0.853	-0.102	0.865
	O	0.853	-0.102	0.865
	T	0.852	-0.168	0.921
Aspen 4	I	0.980	0.009	0792
	M	0.980	0.004	0794
	O	0.980	0.004	0794
	T	0.983	-0.009	0.820
Aspen 5	I	0.981	0.022	0.857
	M	0.974	0.005	0.897
	O	0.974	0.005	0.897
	T	0.984	-0.007	0.891
Aspen 6	I	0.956	-0.087	0.898
	M	0.986	-0.063	0.953
	O	0.986	-0.063	0.953
	T	0.984	-0.090	0.965
Aspen 7	I	0.969	-0.057	0.766
	M	0.972	-0.100	0.870
	O	0.972	-0.100	0.870
	T	0.975	-0.084	0.837
Aspen 8	I	0.977	0.004	0.891
	M	0.988	-0.035	0.902
	O	0.988	-0.035	0.902
	T	0.984	-0.036	0.905
Aspen 9	I	0.978	-0.013	0.754
	M	0.982	0.018	0.734
	O	0.982	0.018	0.734
	T	0.983	-0.007	0.745
Aspen 10	I	0.977	0.013	0.777
	M	0.983	-0.011	0.838
	O	0.983	-0.011	0.838
	T	0.982	-0.012	0.819
Aspen 11	I	0.990	-0.006	0.854
	M	0.976	-0.006	0.864
	O	0.976	-0.006	0.864
	T	0.988	-0.015	0.854

(continued)

Table 2 (continued)

		r^2	A	B
Aspen 12	I	0.973	-0.016	0.889
	M	0.976	-0.023	0.911
	O	0.976	-0.023	0.911
	T	0.981	-0.028	0.913
Aspen 13	I	0.960	-0.141	0.879
	M	0.978	-0.140	0.978
	O	0.978	0.140	0.978
	T	0.967	-0.168	0.951
Birch 1	I	0.738	-0.116	0.898
	M	0.763	0.065	0.825
	O	0.763	0.065	0.825
	T	0.776	-0.023	0.854
Birch 2	I	0.384	0.755	0.534
	M	0.605	0.561	0.877
	O	0.605	0.561	0.877
	T	0.587	0.595	0.798
Birch 3	I	0.946	-0.292	1.033
	M	0.938	-0.436	1.213
	O	0.938	-0.436	1.213
	T	0.961	-0.324	1.103
Birch 4	I	0.954	0.016	0.963
	M	0.964	-0.211	0.995
	O	0.964	-0.211	0.995
	T	0.978	-0.098	0.962
Birch 5	I	0.973	-0.065	0.815
	M	0.956	-0.000	0.907
	O	0.956	0.000	0.907
	T	0.975	0.019	0.873
Birch 6	I	0.973	-0.065	0.815
	M	0.978	-0.128	0.957
	O	0.978	-0.128	0.957
	T	0.975	-0.106	0.878
Birch 7	I	0.831	0.136	1.036
	M	0.963	-0.079	1.078
	O	0.963	-0.079	1.078
	T	0.968	-0.005	1.056
Birch 8	I	0.893	0.182	1.137
	M	0.979	-0.079	1.009
	O	0.979	-0.079	1.009
	T	0.960	-0.105	1.011
Birch 9	I	0.931	0.012	1.114
	M	0.902	-0.013	0.981
	O	0.902	-0.013	0.981
	T	0.969	-0.002	1.025
Birch 10	I	0.959	-0.298	1.088
	M	0.966	0.024	0.910
	O	0.966	0.024	0.910
	T	0.966	-0.085	0.987

(continued)

Table 2 (continued)

		r^2	A	B
Birch 11	I	0.968	-0.098	1.101
	M	0.982	0.010	0.966
	O	0.982	0.010	0.966
	T	0.981	-0.031	1.037
Birch 12	I	0.943	-0.200	0.838
	M	0.979	-0.156	0.969
	O	0.979	-0.156	0.969
	T	0.980	-0.197	0.968
Birch 13	I	0.955	-0.027	0.783
	M	0.983	-0.092	0.983
	O	0.983	-0.092	0.983
	T	0.973	-0.057	0.885
Oak 1	I	0.607	0.331	0.753
	M	0.539	0.541	0.725
	O	0.539	0.541	0.725
	T	0.580	0.416	0.757
Oak 2	I	0.760	-0.151	0.846
	M	0.777	-0.061	0.830
	O	0.777	-0.061	0.830
	T	0.771	-0.116	0.849
Maple 1	I	0.809	0.142	0.669
	M	0.863	0.173	0.828
	O	0.863	0.173	0.828
	T	0.852	0.144	0.747
Maple 2	I	0.850	-0.188	0.783
	M	0.853	-0.051	0.934
	O	0.853	-0.051	0.934
	T	0.860	-0.139	0.903
Maple 3	I	0.822	0.058	0.578
	M	0.849	0.123	0.703
	O	0.849	0.123	0.703
	T	0.840	0.098	0.640
Spruce 1	I	0.840	-0.189	0.713
	M	0.856	-0.054	0.787
	O	0.856	-0.054	0
	T	0.854	-0.082	0.715
Spruce 2	I	0.784	0.125	0.619
	M	0.799	0.392	0.649
	O	0.799	0.392	0.649
	T	0.820	0.241	0.659
Fir 1	I	0.806	0.043	0.564
	M	0.836	0.112	0.798
	O	0.836	0.112	0.798
	T	0.855	0.037	0.784
Fir 2	I	0.710	0.028	0.560
	M	0.792	0.046	0.941
	O	0.792	0.046	0.941
	T	0.810	0.045	0.670

(continued)

Table 2 (continued)

	r^2		A	B
Fir 3	I	0.832	0.303	0.681
	O	0.846	0.303	0.681
	T	0.879	0.189	0.719
Pine 1	I	0.842	-0.146	0.987
	M	0.908	-0.046	0.916
	O	0.908	-0.046	0.916
	T	0.887	-0.066	0.918
Pine 2	I	0.798	-0.265	1.071
	M	0.843	-0.010	0.702
	O	0.843	-0.010	0.722
	T	0.836	-0.126	0.860

Generally, more open canopies such as aspen and birch are typified by larger amounts of TF, intermediately dense canopies like oak, maple, white pine have substantial amounts of TF, whereas dense canopy trees like spruce and fir have limited TF. From 1976 data the minimum rainfall to obtain measurable TF ranged from 0.5 mm for a birch to 3.2 mm for a spruce. Additional interception (precipitation that never reaches the ground) occurs during the initial period of rainfall as the bark and leaves absorb water.

Experimental measures of water absorption by samples of bark, indicate a rapid absorption during the initial 2-4 minutes of exposure to water. Saturation is approached within 30 minutes. The amount of absorption (saturation level) was quite variable (10-60% of weight of water to weight of bark with a mean of 30%) and revealed no consistent patterns among species.

Germination and Growth

Of the 7 taxa typically used in roadside plantings, Lolium perenne displayed the greatest tolerance to water stress, reached the highest percentage of germination and had the highest germination index (a combination of maximum percentage germination and the rate of germination) (Table 3). F. elatior, F. rubra and Lotus cornicnlatus were intermediate with respect to water stress, final germination percentage and germination index. Coronilla, varia and Poa pratensis responded poorly in all three parameters.

The effect of soil pH on growth of F. rubra, F. elatior, L. perenne and B. inermis generally is to show improved growth for all but F. elatior in soils having the pH adjusted to either pH 7.3 or 8.6 (Table 4). The measures of plant water potential, both xylem water potential and leaf water potential failed to demonstrate any stress corresponding to the different pH regimes.

The quantity of phytomass acquired in the 3 week period parallels the germination vigor of the 4 species.

Additions of organic carbon to the soil revealed significant differences in growth depending on the source of carbon. For most of the species tested, the addition of 2% or 4% peat moss to the clay soil resulted in a significant stimulation in the early growth of the plants whereas similar additions of aspen leaves diminished the growth. This pattern was often enhanced with the addition of nutrients. Significant reduction in height (Figure 4), fresh and dry weight and chlorophyll content of P. pratensis, F. elatior, F. rubra, and L. cornicutatus suggest a significant allelopathic response to aspen leaves (Olson, Kapustka, Koch; unpublished data).

TABLE 3. Germination Index (a) and Mean Cumulations Percentages Germination (b) of Roadside Species Under Water Stress Conditions.

		WATER POTENTIAL (4) 0	1	3	5	7	10	15
Lolium perenne	a	94.2	80.7	73.8	79.2	69.2	37.3	2.3
	b	92.4	91.6	86.4	90.0	89.6	72.0	16.4
Festuca elatior	a	41.4	32.6	19.8	17.0	9.3	2.4	0
	b	80.4	68.8	57.2	52.8	41.2	10.8	0
F. rubra	a	62.1	49.5	47.0	37.4	25.6	4.2	0.1
	b	85.6	82.4	82.0	74.0	60.0	23.2	0.4
Bromus inermis	a	16.7	15.0	12.7	12.0	9.5	7.3	0.9
	b	40.4	38.0	35.2	36.4	33.2	31.6	4.4
Poa pratensis	a	37.6	19.4	18.6	3.6	2.1	0	0
	b	70.8	54.4	54.0	25.6	16.8	0	0
Lotus corniculatus	a	48.0	43.4	48.9	38.4	12.9	0.4	0.1
	b	66.4	64.4	66.4	63.2	30.8	3.2	0.4
Coronilla varia	a	5.7	6.5	3.5	1.1	0.5	0.2	0
	b	36.4	37.6	28.4	9.6	6.0	1.6	0

TABLE 4. Mean Dry Weight (mg) Per Plant After 3 Weeks Growth in 3 pH Conditions.

	pH 7.3	8.1	8.6
Festuca elatior	8.9	10.3	8.2
F. rubra	7.2	5.6	6.2
Loliym perenne	11.1	10.6	12.4
Bromus inermis	3.9	3.4	3.5

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APPENDIX I

WEATHER SUMMARIES LITTLE BALSAM CREEK

Week Ending	Ambient Temp (^{o}C)	Relative Humidity %	Solar Insolation cal·um^{-2}·da^{-1}	Anemometer km-wk^{-1}
12 Apr. 1976	6.0	58.7	423	550.9
19 Apr. 1976	10.5	72.8	307	823.1
26 Apr. 1976	4.6	73.4	285	567.2
3 May 1976	7.0	63.7	324	542.3
10 May 1976	11.9	48.4	485	122.3
17 May 1976	11.8	60.5	426	296.2
24 May 1976	12.0	65.1	517	301.9
31 May 1976	11.2	81.5	304	176.0
7 June 1976	16.4	64.1	492	301.7
14 June 1976	19.3	76.9	434	458.8
21 June 1976	16.4	70.2	387	840.3
28 June 1976	16.6	71.2	457	291.0
5 July 1976	17.9	69.4	471	113.8
12 July 1976	19.9	77.0	434	138.7
19 July 1976	20.2	72.7	456	232.9
26 July 1976	21.4	73.5	500	253.5
2 Aug 1976	18.8	71.9	481	113.8
9 Aug 1976	18.2	72.4	248	244.3
16 Aug 1976	17.5	77.8	413	171.8
23 Aug 1976	22.8	65.6	317	486.1
30 Aug 1976	18.5	15.8	392	394.3
6 Sept 1976	17.6	62.6	367	405.8
13 Sept 1976	18.5	69.2	309	747.2
20 Sept 1976	12.0	73.7	264	149.9
10 Apr 1977	2.8	62.1	415	439.4
17 Apr 1977	6.8	77.9	345	264.2
24 Apr 1977	8.0	73.6	355	262.6
1 May 1977	12.0	51.4	543	706.9
8 May 1977	9.2	59.8	535	390.7
15 May 1977	14.5	63.2	486	333.7
22 May 1977	15.1	82.1	421	196.0
29 May 1977	14.9	75.1	472	178.5
5 June 1977	14.6	79.9	435	151.9
12 June 1977	12.3	75.8	523	180.6
19 June 1977	15.1	81.2	465	160.5
26 June 1977	18.6	73.4	517	90.8
3 July 1977	19.1	74.8	424	328.4
10 July 1977	17.7	78.0	393	51.7
17 July 1977	19.7	78.5	450	195.4
24 July 1977	21.9	74.7	466	209.1
31 July 1977	16.7	35.4	392	143.1
7 Aug 1977	17.0	76.9	394	229.6

(continued)

Appendix I (continued)

Week Ending	Ambient Temp (°C)	RFL Humidity %	Solar Insolation $cal \cdot um^{-2} \cdot da^{-1}$	Anemometer $km\text{-}wk^{-1}$
14 Aug 1977	16.3	75.0	452	22.0
21 Aug 1977	14.1	77.3	216	70.7
28 Aug 1977	16.0	79.6	275	256.4
4 Sept 1977	16.2	82.6	N.A.	239.6
11 Sept 1977	14.0	83.8	238	321.4
18 Sept 1977	13.3	82.6	265	95.1
25 Sept 1977	9.7	90.4	N.A.	N.A.
2 Oct 1977	10.5	57.3	260	1301.7*
9 Oct 1977	6.9	80.1	230	417.3
16 Oct 1977	6.8	64.1	201	543.7
23 Oct 1977	6.2	64.9	167	307.8
30 Oct 1977	10.0	65.7	131	307.5
6 Nov 1977	6.2	N.A.	147	203.7
14 Nov 1977	2.7	N.A.	N.A.	538.4

*Value is for 2 week period.

APPENDIX II

Soil Temperature Profiles

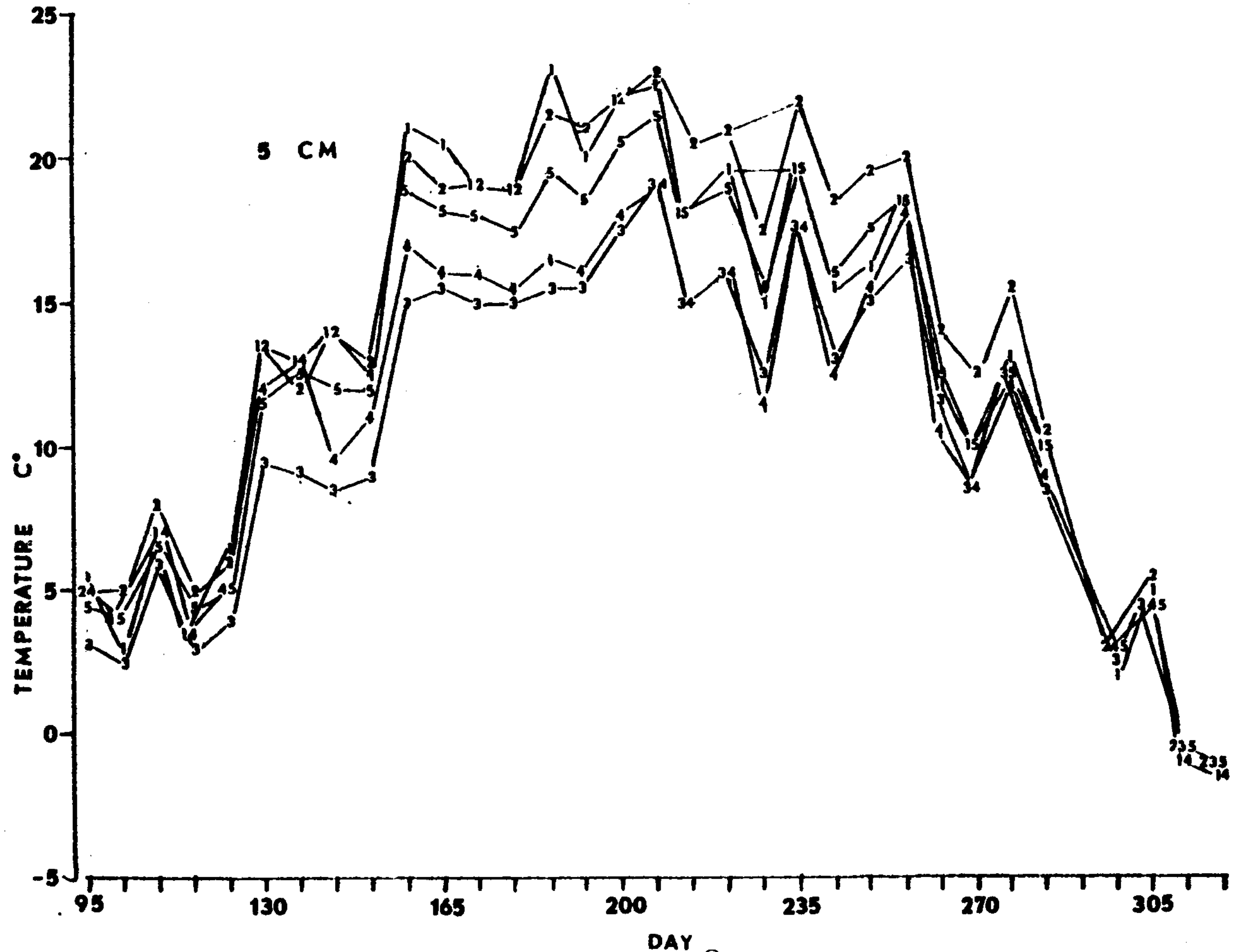

Figure 1. Weekly Soil Temperature (^{O}C) at Five Sites; (1) Grass, (2) Pasture, (3) Pine, (4) Maple, (5) Birch at 5 cm Depth.

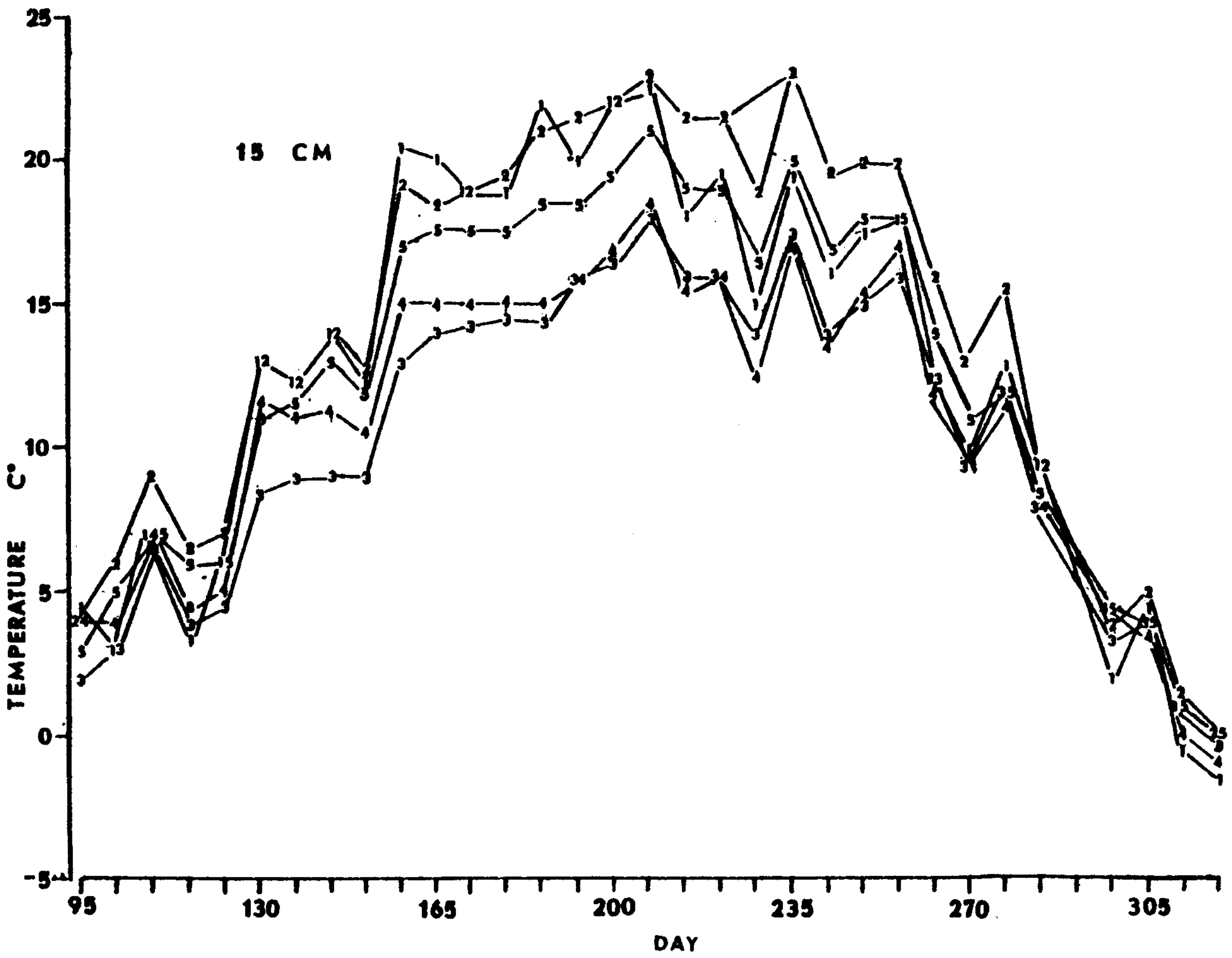

Figure 2. Weekly Soil Temperature (^{o}C) at 15 cm Depth.

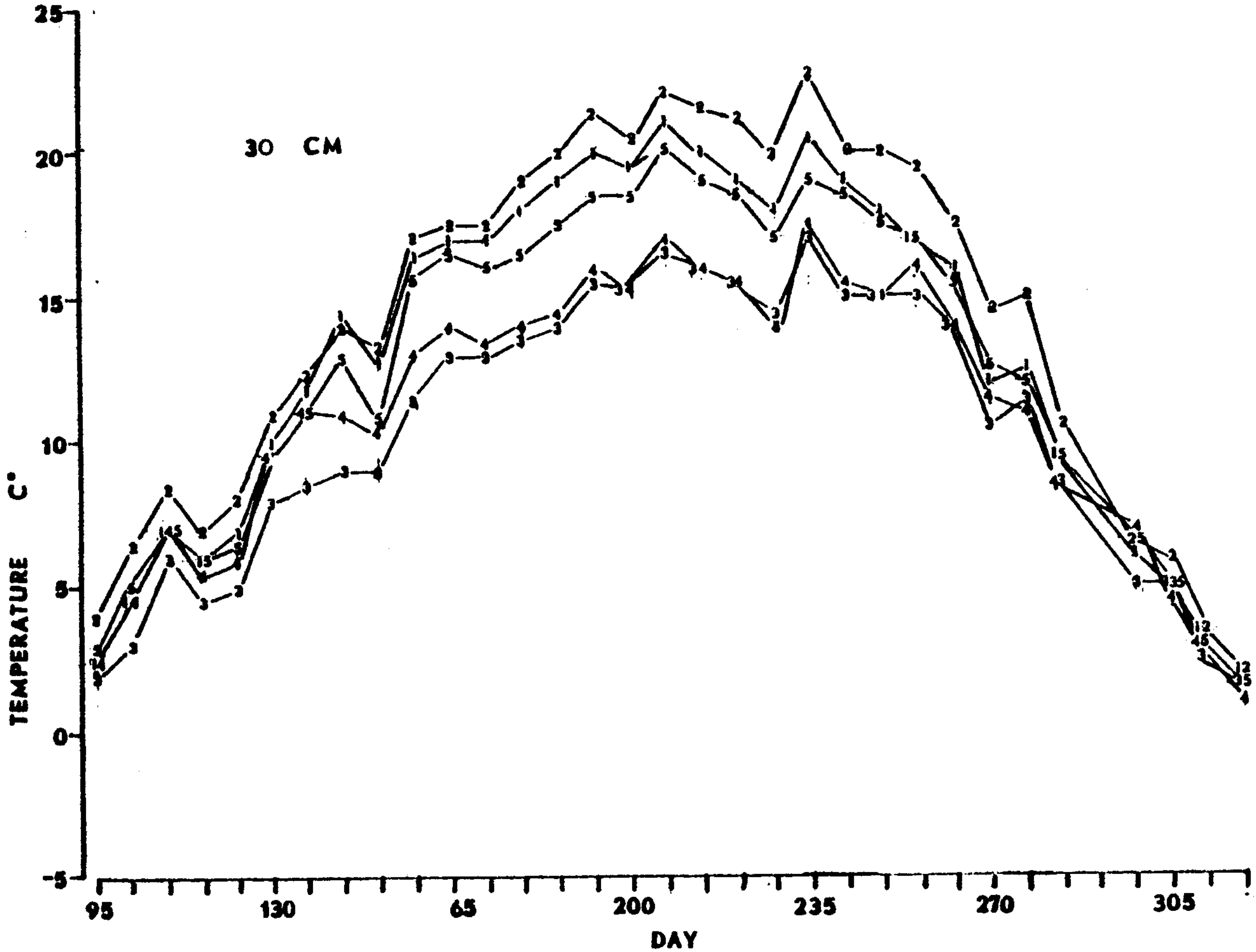

Figure 3. Weekly Soil Temperature (^{O}C) at 30 cm Depth.

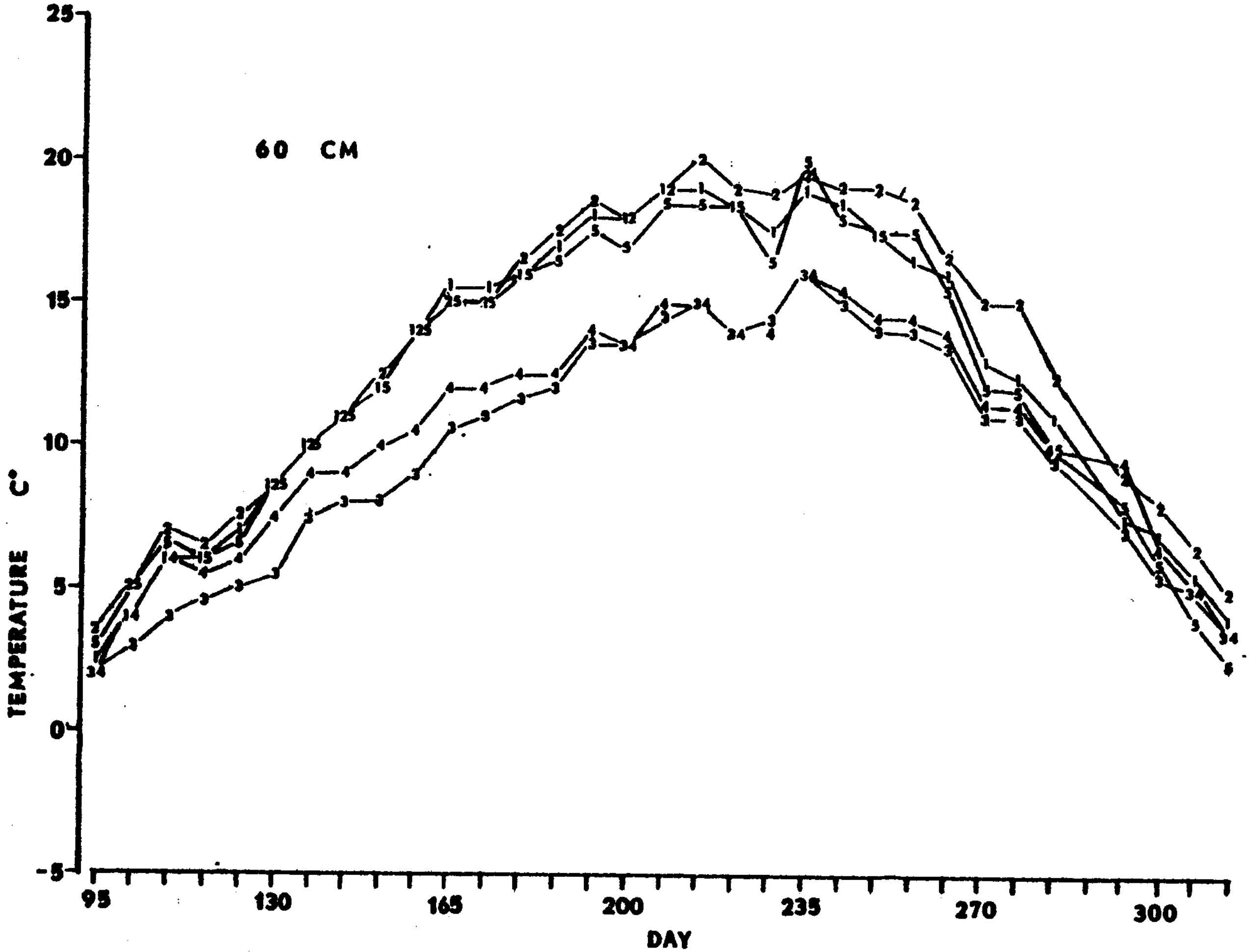

Figure 4. Weekly Soil Temperature (°C) at 60 cm Depth.

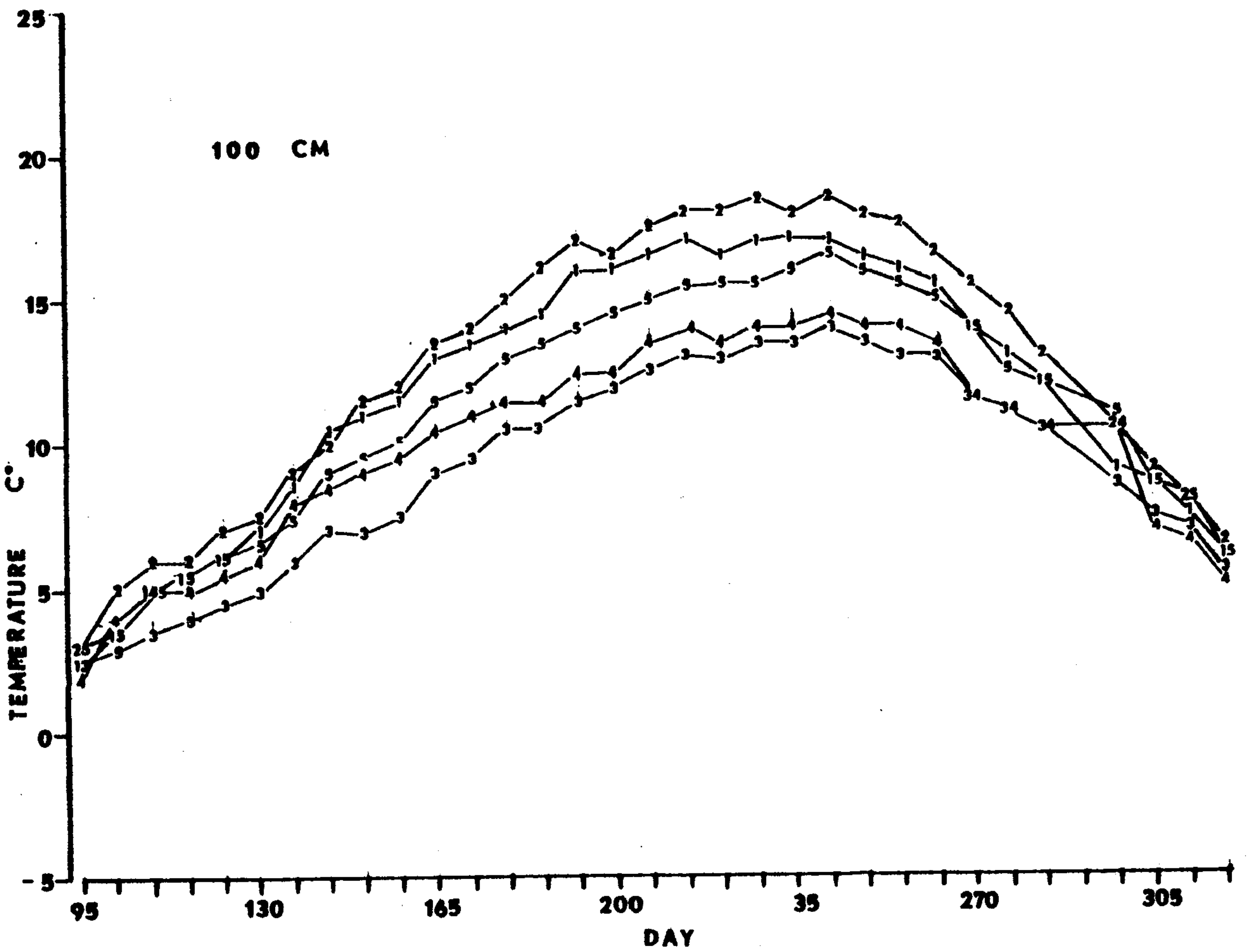

Figure 5. Weekly Soil Temperature (^{o}C) at 100 cm Depth.

APPENDIX III

Soil Moisture Profiles

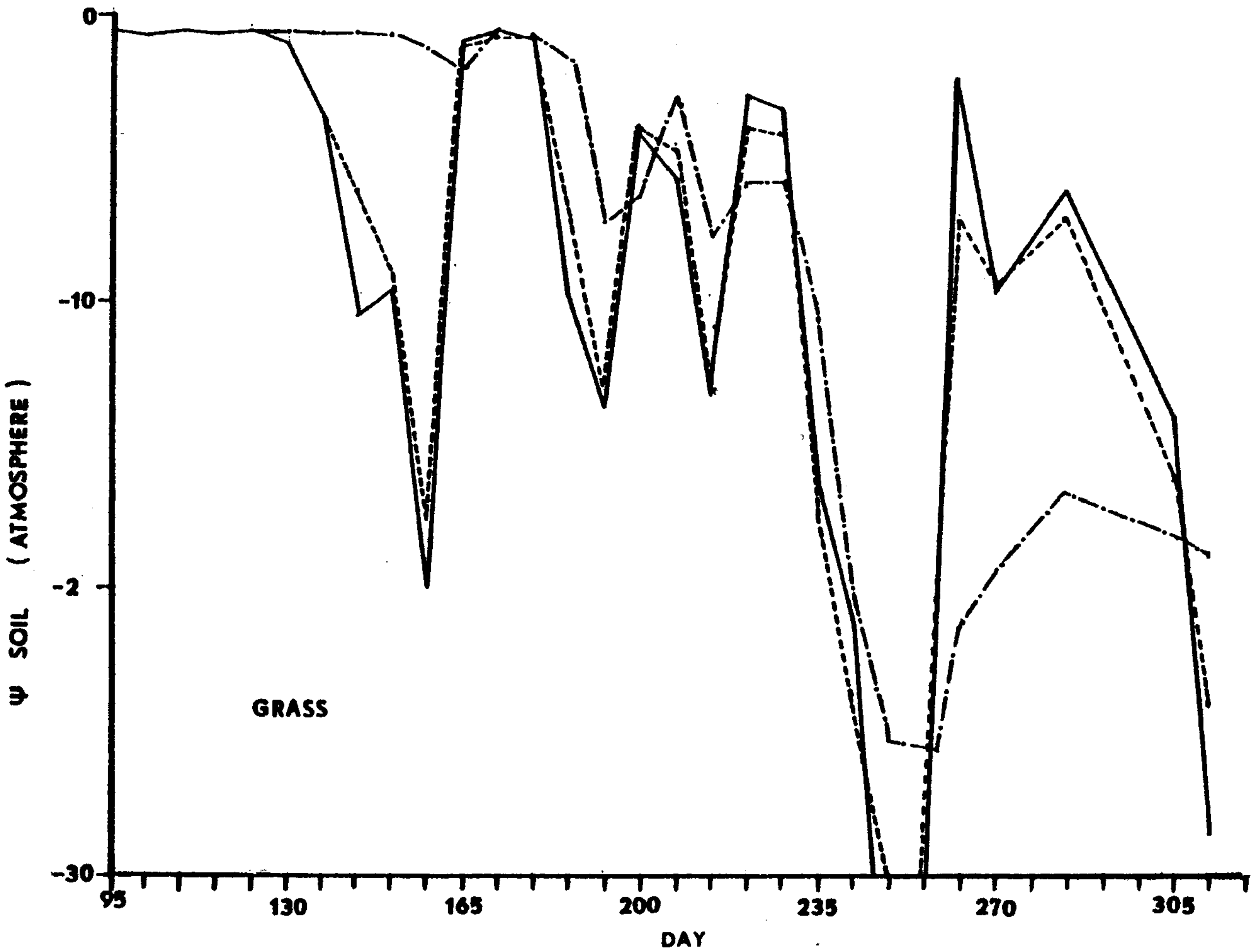

Figure 6. Weekly Soil Moisture Conditions (Ψ Soil) at 5 cm (——), 15 cm (---) and 30 cm (—·—) Depth.

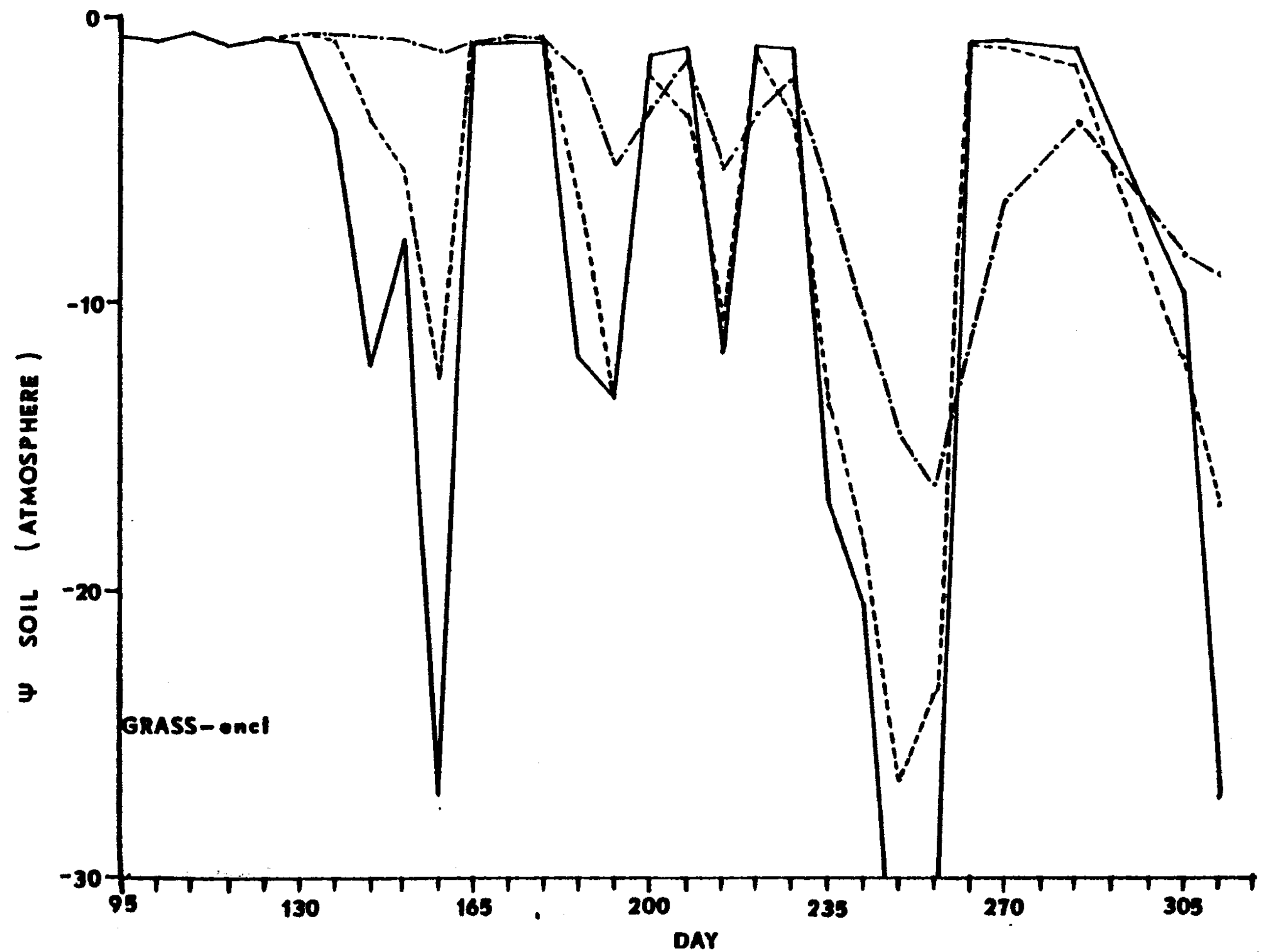

Figure 7. Weekly Soil Moisture Conditions (Ψ Soil) at 5 cm (——), 15 cm (---) and 30 cm (–·–) Depth.

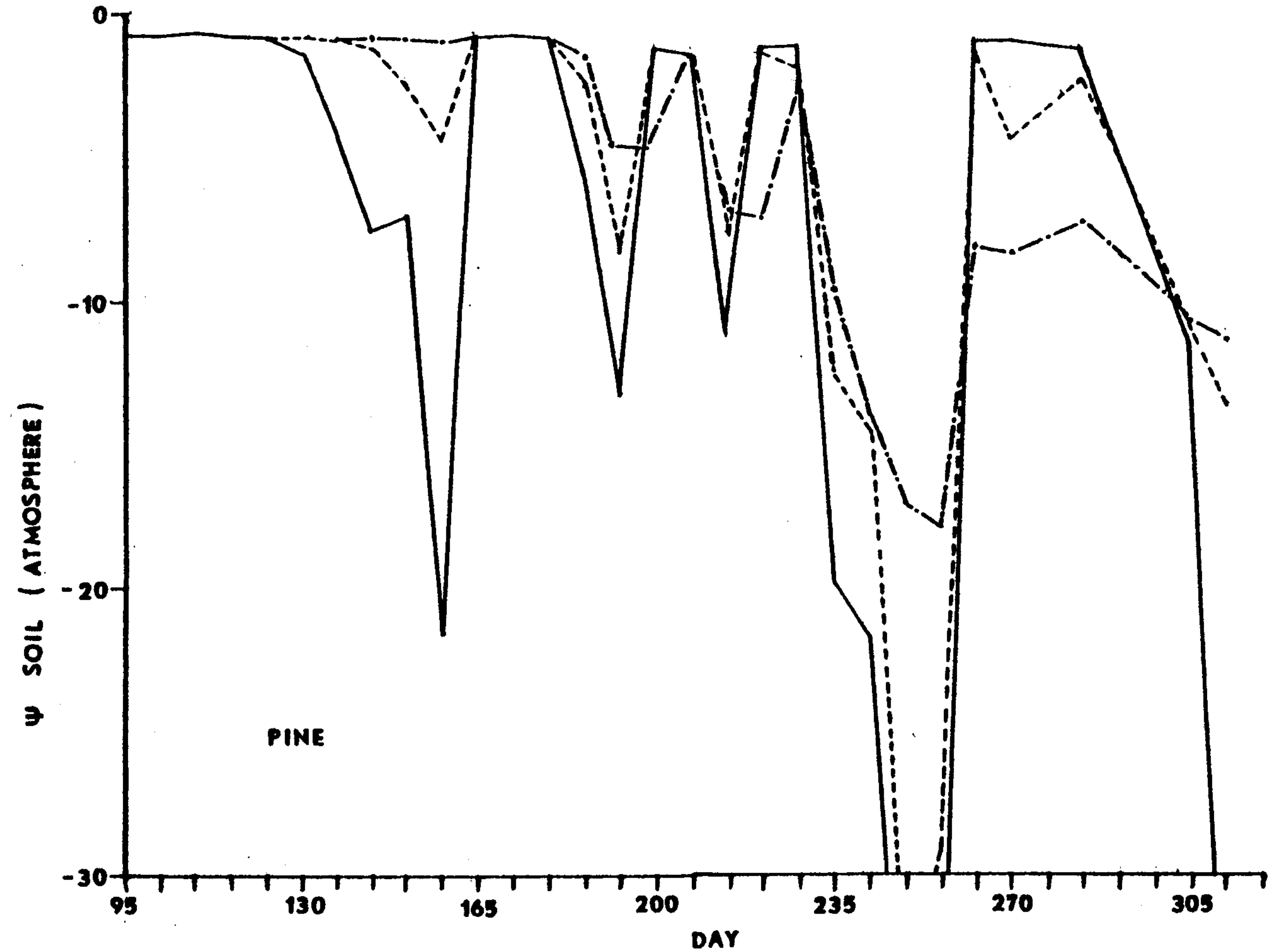

Figure 8. Weekly Soil Moisture Conditions (Ψ Soil) at 5 cm (——), 15 cm (---) and 30 cm (—·—) Depth.

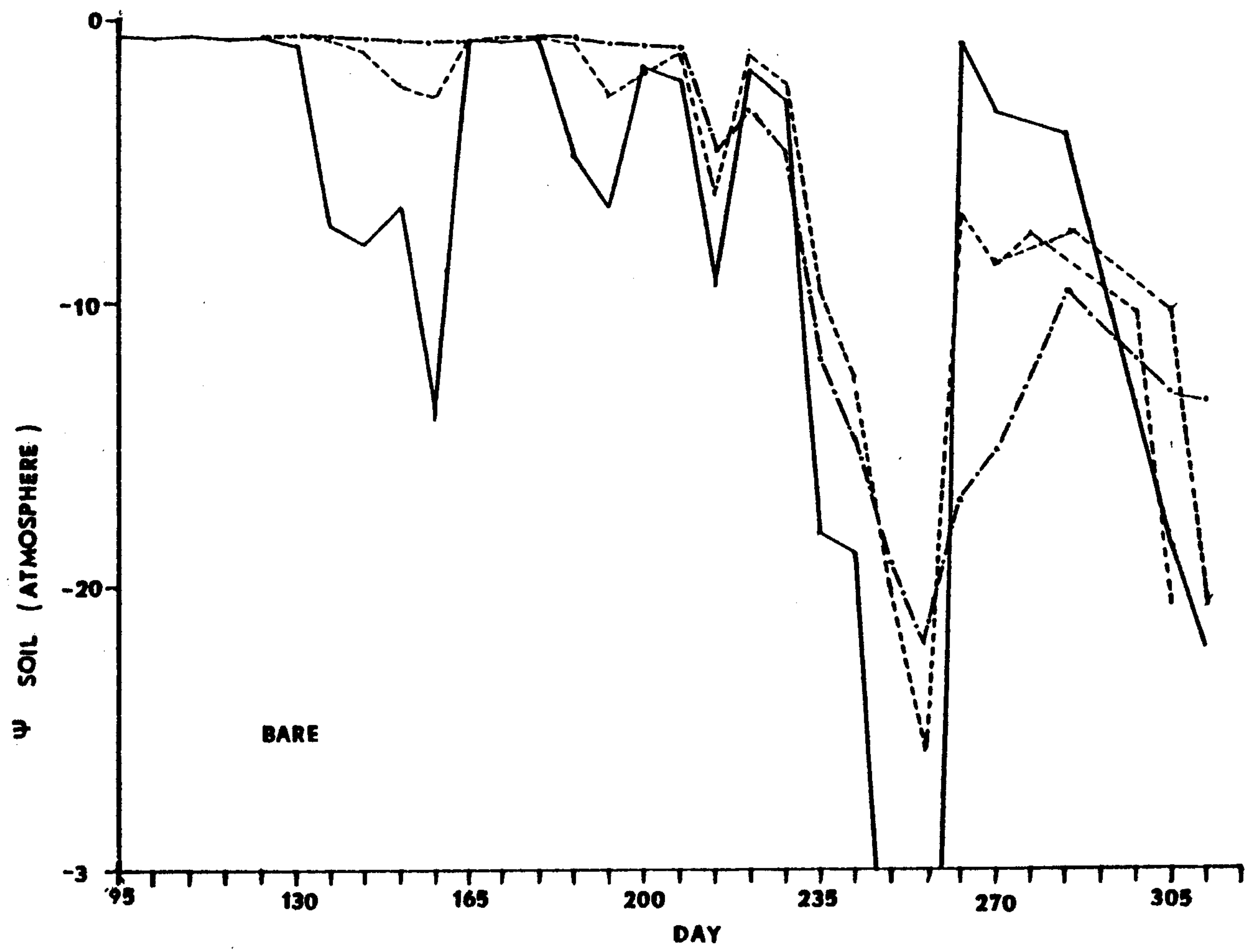

Figure 9. Weekly Soil Moisture Conditions (Ψ Soil) at 5 cm (——), 15 cm (---) and 30 cm (—·—) Depth.

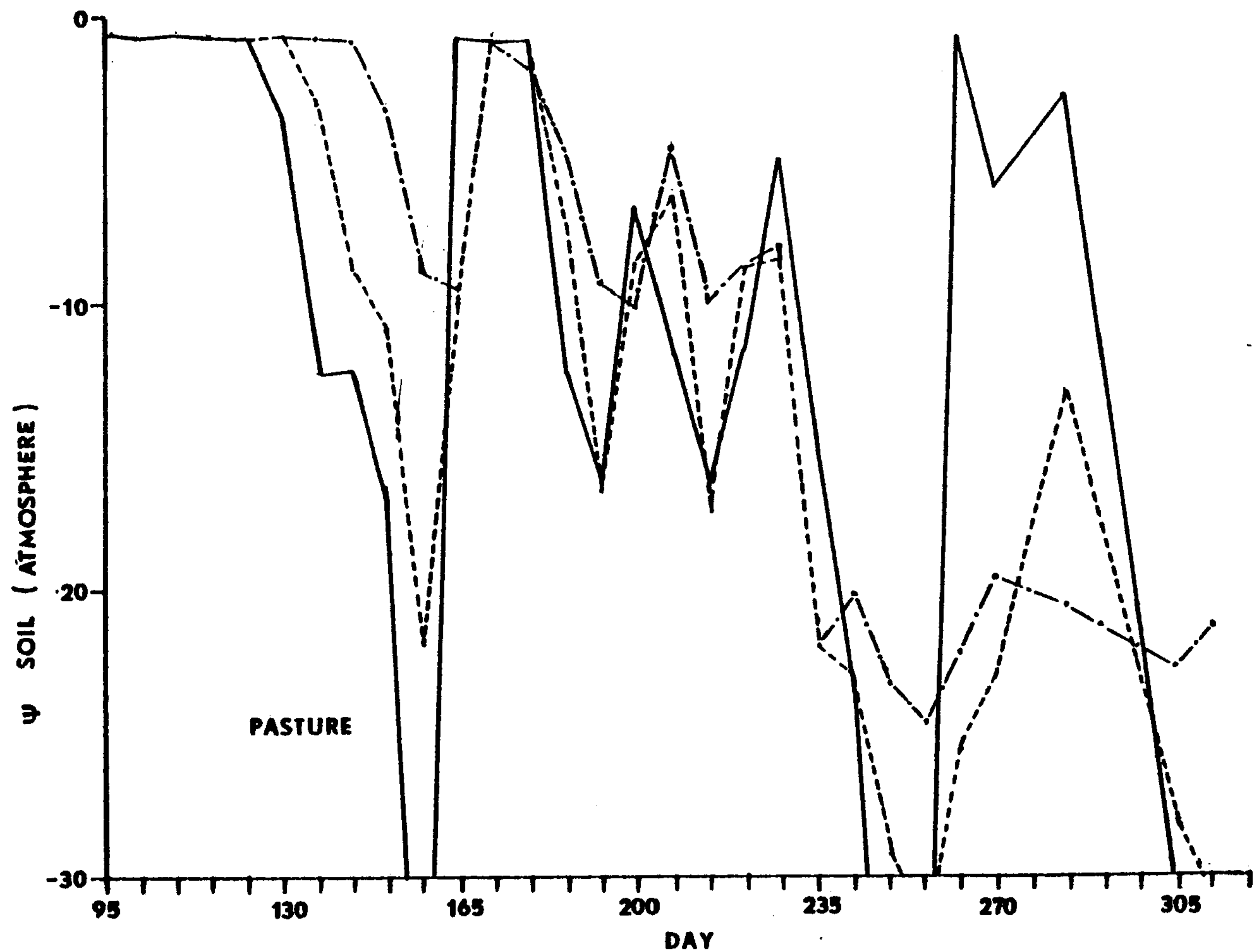

Figure 10. Weekly Soil Moisture Conditions (Ψ Soil) at 5 cm (——), 15 cm (---) and 30 cm (—·—) Depth.

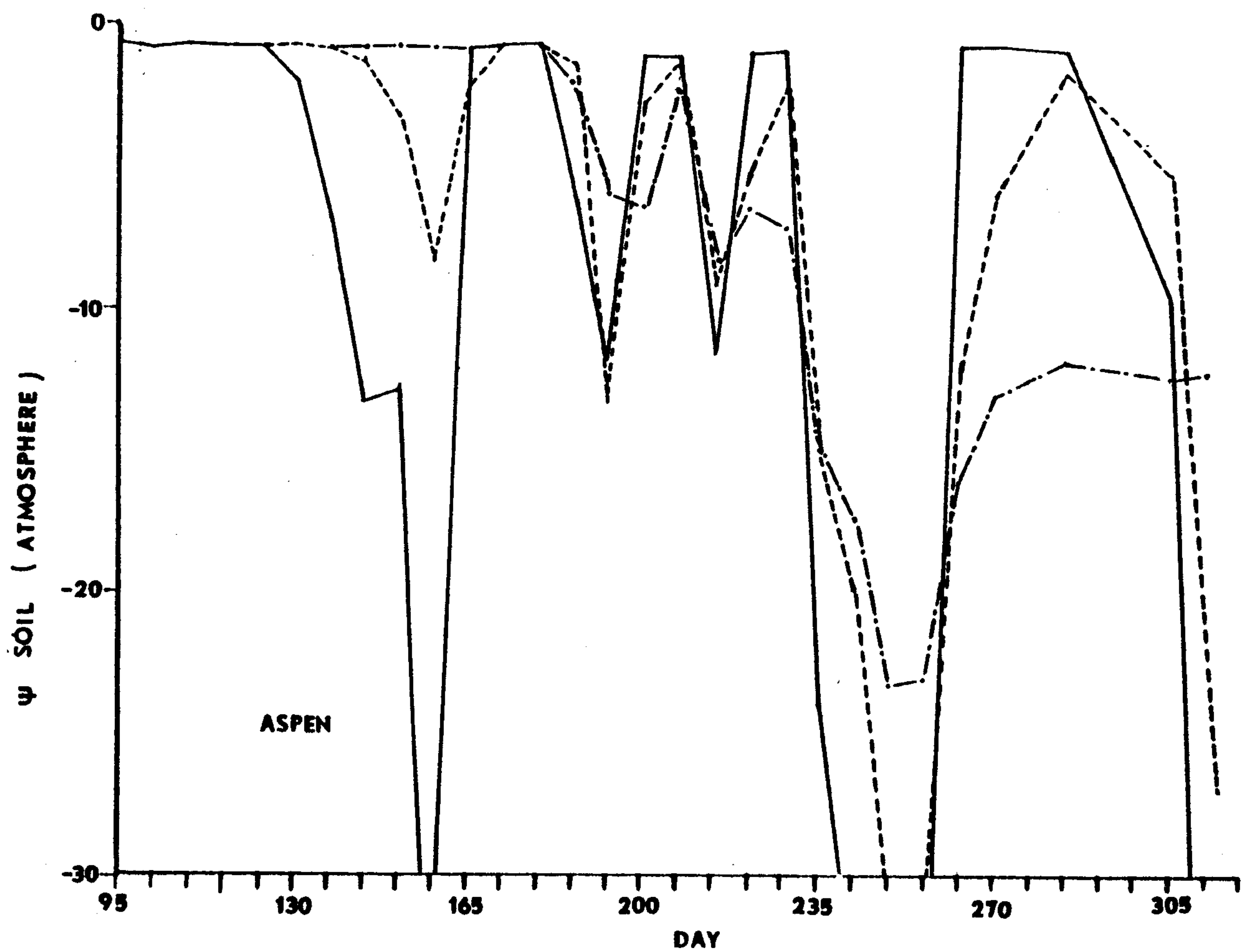

Figure 11. Weekly Soil Moisture Conditions (Ψ Soil) at 5 cm (——), 15 cm (---) and 30 cm (–·–) Depth.

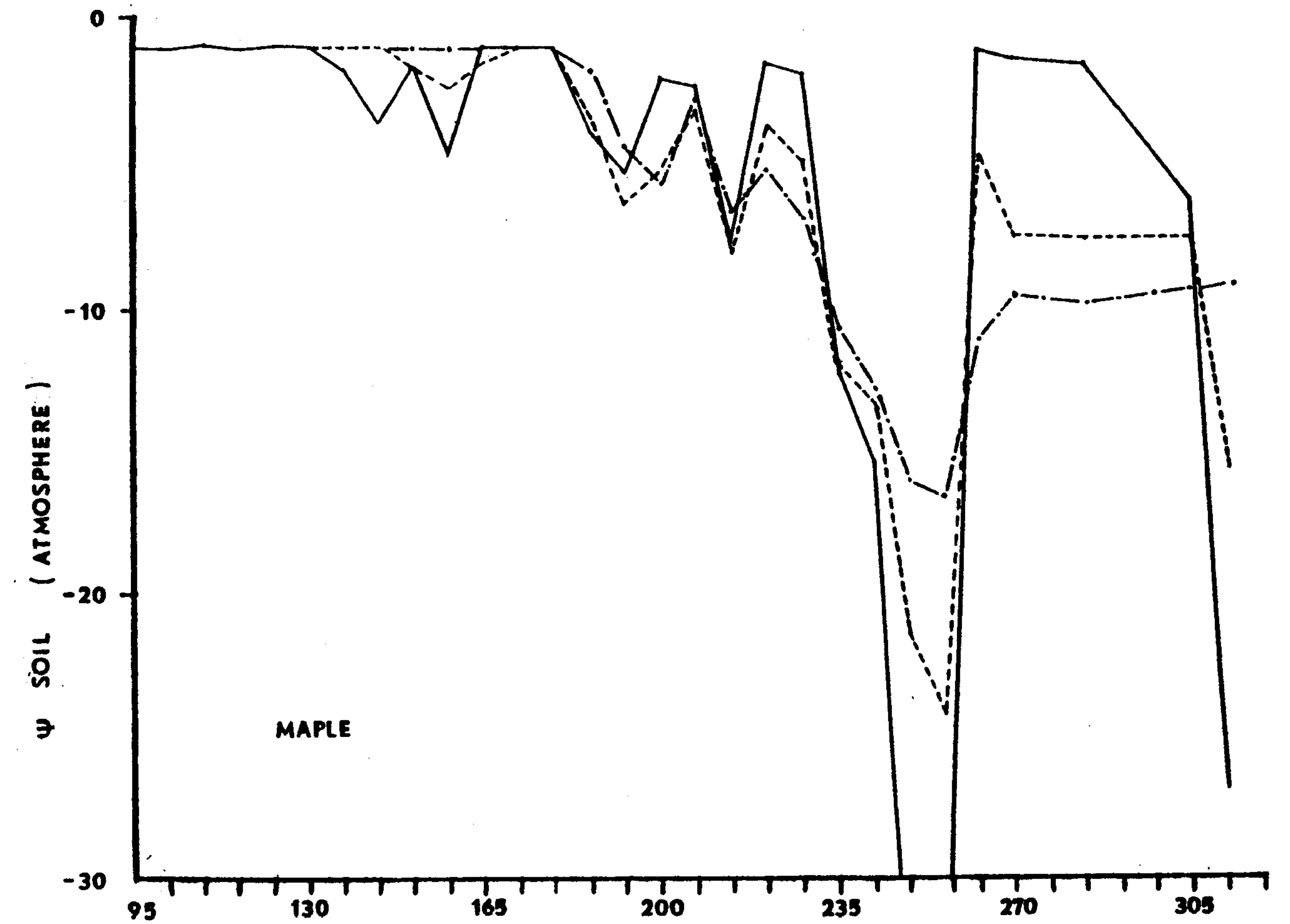

Figure 12. Weekly Soil Moisture Conditions (Ψ Soil) at 5 cm (——), 15 cm (---) and 30 cm (—·—) Depth.

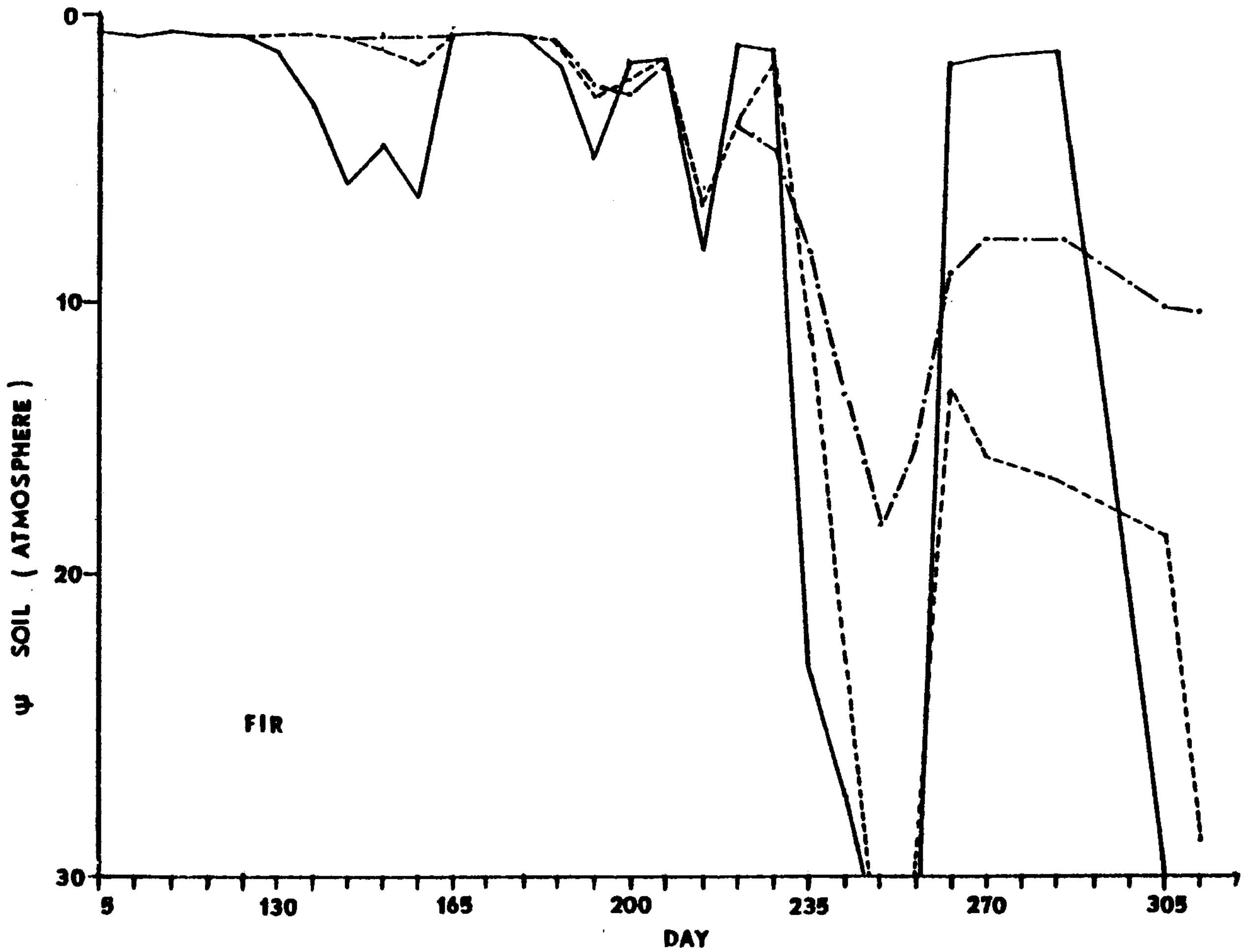

Figure 13. Weekly Soil Moisture Conditions (Ψ Soil) at 5 cm (——), 15 cm (---) and 30 cm (—·—) Depth.

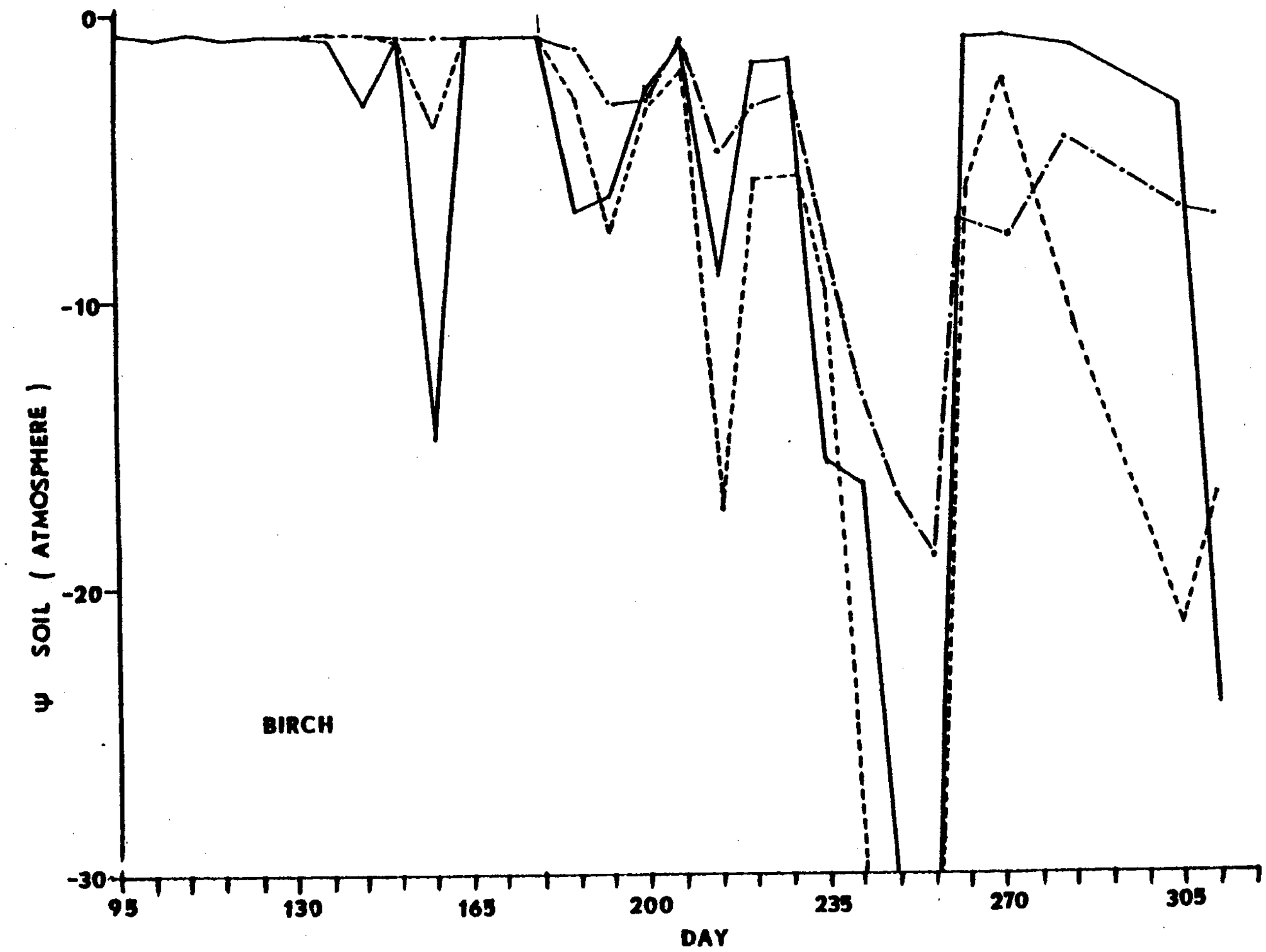

Figure 14. Weekly Soil Moisture Conditions (Ψ Soil) at 5 cm (——), 15 cm (---) and 30 cm (—·—) Depth.

ROLE OF PLANT ROOTS IN RED CLAY EROSION

Lawrence A. Kapustka and Donald W. Davidson

The objective of this study was to determine the extent that root systems of prevailing trees, shrubs and other vegetation retard the erosion of red clay soils. The principle focus was the possible role of roots in retarding slump erosion at selected sites along the Little Balsam and Skunk Creek sub-basins of the Nemadji River Basin which drains into western Lake Superior.

Our efforts were directed at correlating the magnitude of slumping erosion with the distribution and strength of roots of selected species and vegetation types. The magnitude of slumping was quantified over a 34 month period by measuring the movement of marker stakes along transects in portions of the Skunk and Little Balsam drainage systems. Root distribution patterns were determined from excavation sites in the vicinity of the transects. Additional measures of surface runoff were obtained to assess the influence of vegetation on surface erosion in areas exhibiting massive slumping activity as well as apparently stable areas.

METHODS

Soil Slumping

In August, 1975 field sites were selected to monitor mass slumping activity at 10 locations in the Little Balsam Creek and 12 locations in the Skunk Creek sub-basins (Figures 1 and 2). Each transect extended from the hill-top above the creek to the stream bank along a compass direction approximately perpendicular to the stream. A series of 50 cm long stakes were driven into the ground, above and below the breaks in the soil surface in areas where breaks occurred, and at regular intervals where there were no apparent failure zones. A variety of vegetational types was selected for the transects with aspen, fir, birch, and grass cover, as well as bare soil represented. The distance from the base point at the top of the transect to each of the down-hill stakes as well as the distance between each of the adjacent stakes was measured. Between 7-22 August 1975, 1-8 November 1975, 15-22 April 1976, 14-21 October 1976 and 12-23 May 1977, 5-11 August 1977, 12 November 1977[1] and 21-23 June 1978. Distances between stakes were recorded to the nearest one-hundredth of a foot (3 mm).

The accuracy of the transect stake measurements was determined by repeated measurements of Little Balsam Transect No. 9. This transect was judged to be as difficult as any to measure due to topographic and vegetational features.

[1]Only LB 5, 6, and 10 were measured.

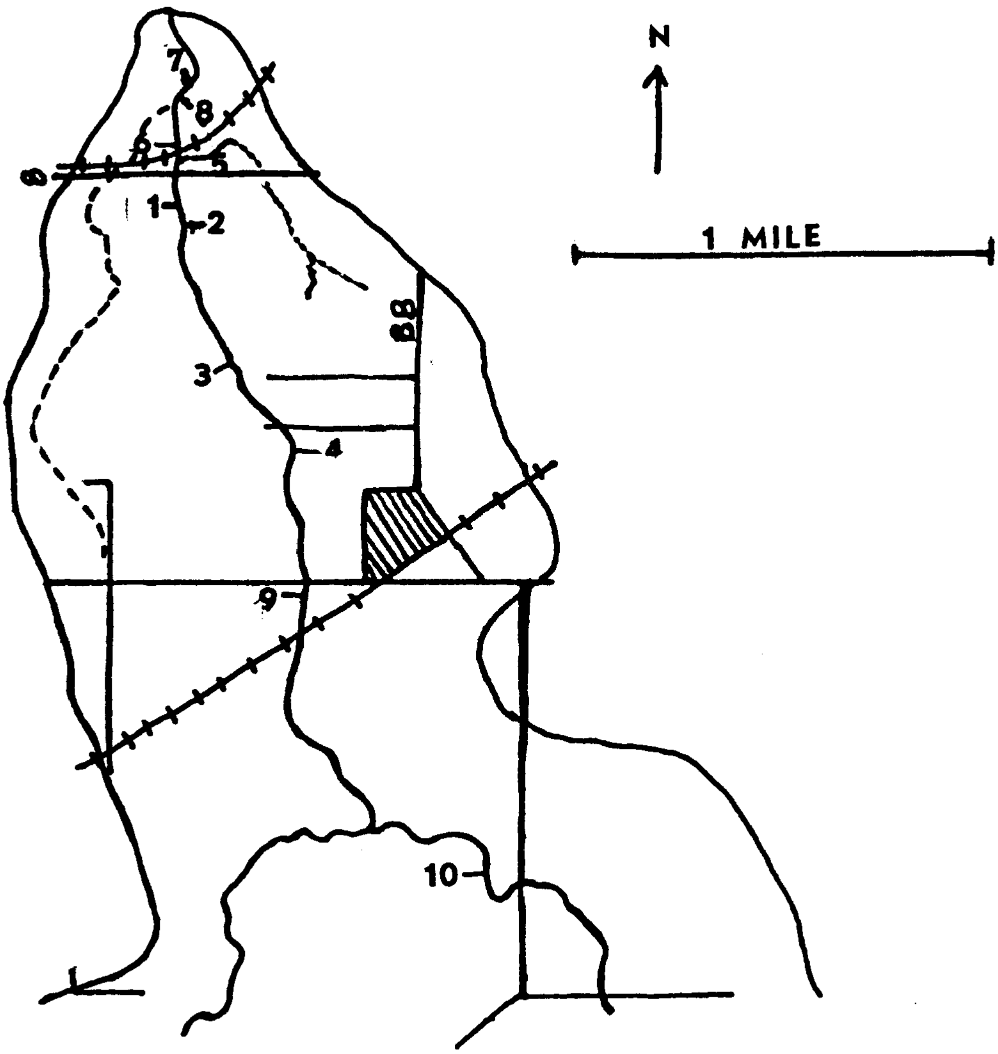

Figure 1: Transect locations in Little Balsam Creek Basin. Runoff entrapments are located near Transects No. 5 (grassy) and No. 8 (woodland).

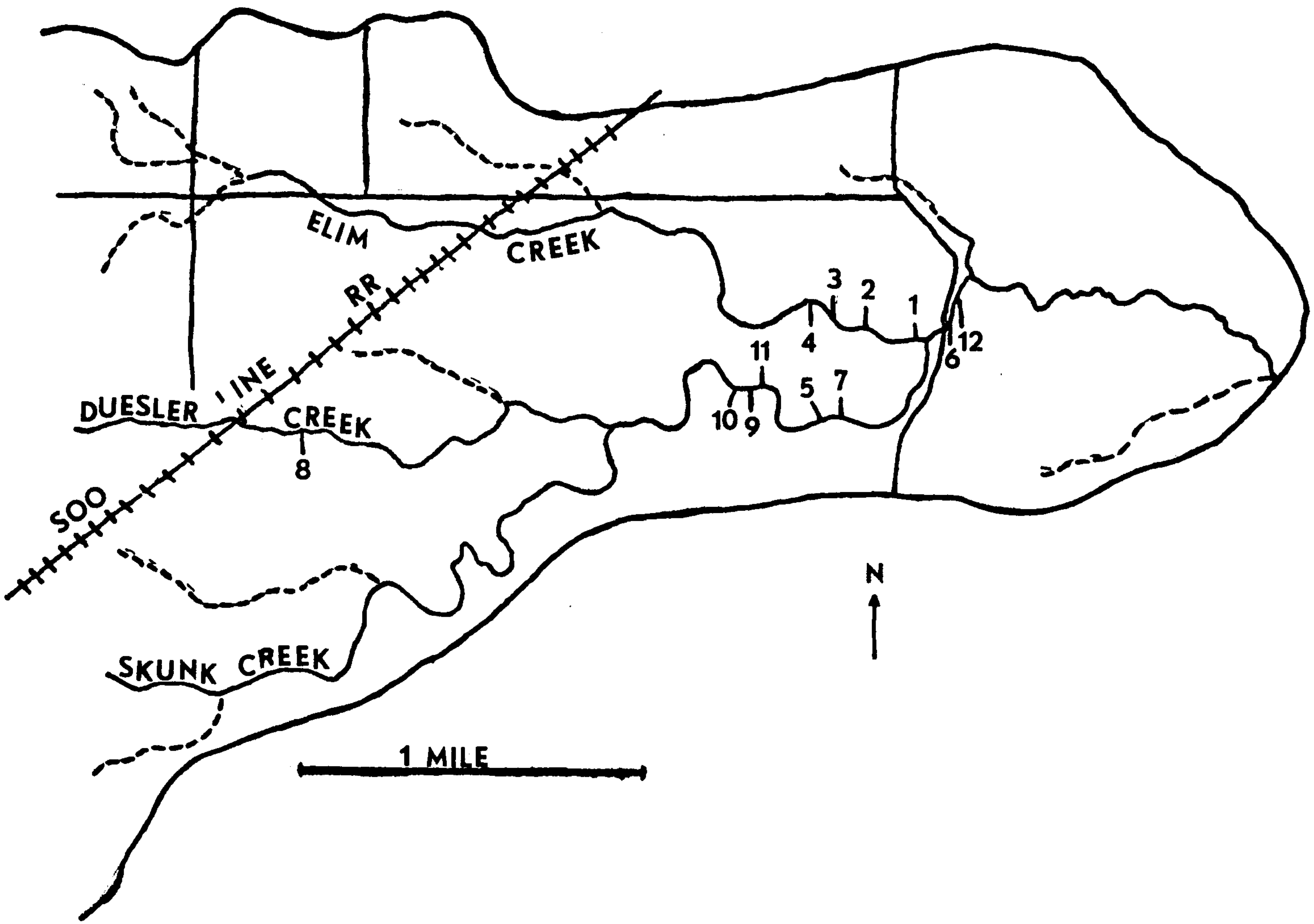

Figure 2: Transect locations in Skunk Creek Basin.

The first of five measurements was designated as the base line, and the deviations from these values in the remaining four measurements were used to calculate the accuracy of measurement. The 95% C.I. of deviation of the between-stake distance was 0.0055 ± 0.0065 ft. (1.7 ± 2.0 mm) while the deviation of measurements from the crest to each stake was 0.0095 ± 0.0065 ft. (2.9 ± 1.7 mm). Consequently, we believe differences in subsequent measurements varying $>|0.02|$ ft. (6.0 mm) indicate movements of the stakes rather than errors in measurements. Differences of $\leq|0.02|$ ft. (6.0 mm) were ignored in our calculations.

Root Distributions

Excavation sites for determining root distribution patterns were located adjacent to 8 of the 22 transects established to quantify the slumping. Up to five quadrat sites (0.5 m wide x 1.0 m long x 0.5 m depth) were identified for each transect to reflect the possible variation in soil and vegetation environment from the crest to the valley. At each site the following measurements and/or samples were taken:

(A) The 0.5 m^2 quadrat served as the center for a larger quadrat (10 m x 10 m) in which a complete census of trees ($\geq$ 10 cm DBH) was conducted. The following information was recorded for each tree: a. species identification; b. geometric position from the center of the inner quadrat; c. DBH; d. approximate canopy height.

(B) Sapling and shrub counts are taken within a 5 m x 5 m quadrat concentric with the excavation quadrat.

(C) The living herbaceous vegetation within the 0.5 m^2 quadrat was clipped at ground level and brought to the lab where it was sorted as to species or general growth forms when taxonomic distribution was difficult. Subsequently, the phytomass (oven dry weight) was determined for each identifiable group.

(D) The litter within the 0.5 m^2 quadrat was collected and treated in the same manner as the herbaceous cover.

(E) Soil and root samples are obtained.

The excavation of the 0.5 m^2 quadrat was accomplished at 10 cm intervals. The visible root material within each 10 cm level was collected and brought to the lab. Adhering soil particles were washed from the roots. Subsequently, the roots were sorted into 12 size-classes based on root diameter (cm): <0.5, 0.5-0.99, 1.0-1.99, 2.0-2.99, 3.0-3.99, 4.0-4.99, 5.0-9.99, 10.0-14.99, 15.0-19.99, 20.0-24.99, 25.0-29.99 and

and 30.0 +. Oven dry weight (odw) of the roots was determined for each size class.

The soil from each 10 cm level was throughly mixed in the field and a subsample (approximately 2 kg) was brought to the lab to extrapolate the total quantity of roots remaining in the soil. The roots in the subsample were carefully removed and sorted into diameter size classes. The mass of the roots from the subsample was adjusted by a multiplication factor (mass of soil excavated ÷ mass of subsample x bulk density of the soil)[2].

The relationship between root length and root mass was determined for roots <5 mm diameter (Table 1). These relationships were used to obtain an estimate of root length as a function of root mass. The length of roots greater than 5 mm diameter are measured to the nearest cm. The root distribution data for each sample therefore consists of: 1, the measured mass of roots retrieved from each depth of each hole; 2, the measured mass of roots retrieved from the corresponding soil subsample; 3, the measured length of roots >5 mm diameter; 4, the calculated length of roots <5 mm diameter.

Table 1. Length-weight relationships for small roots.

Size Class Diameter (mm)	$\overline{X} \pm t_{05} S_{\overline{x}}$ ($cm \cdot g^{-1}$)	$S_x/\overline{X} \times 100$
<0.5	1269.7 ± 118.8	3.47
0.5 - 0.99	297.7 ± 33.9	4.24
1.0 - 1.99	93.5 ± 14.1	5.68
2.0 - 2.99	40.0 ± 4.4	4.16
3.0 - 3.99	19.3 ± 2.0	3.80
4.0 - 4.99	13.1 ± 2.6	7.08

Soils

Approximately 0.5 kg of the soil sample previously described was passed through a 2.0 mm sieve. Aliquots of the soils are oven dried at 105° with forced air ventilation for 48 h to obtain the odw. All subsequent calculations

[2]Bulk density values used for the various soil textures were: sand, 0.95; sandy clay loam, 1.00; sandy clay, 1.05; clay, 1.10.

involving soil mass were based on odw. Textural analysis (1) was performed on the screened soils. Soil organic carbon content (Walkley and Black Value) was determined according to the methods outlined by Piper (2). Soil pH values are determined according to procedures of Rice (3). Exchangeable Ca, K and Mg were determined for samples from Skunk Creek Transect 6 and Little Balsam Transect 10 according to procedures of the Perkin-Elmer Corporation (4).

Surface Erosion

Four sites in the vicinity of Little Balsam Creek (Transects 5 and 8) were chosen to represent: 1, tree cover - no slumping; 2, tree cover - slumping; 3, herbaceous cover - no slumping; 4, herbaceous cover - slumping.

At each site, five enclosures (1.0 m wide x 2 m long) characterized by different slope and vegetative cover were constructed to monitor surface erosion during 1976 and 1977. The perimeters were defined with galvanized metal roofing, partially buried leaving an ∿15 cm border above the soil surface. A polyurethane border was added between the metal and the ground surface to insure a proper seal. At the base of each enclosure, the surface runoff was collected in 20 ℓ polyethylene carboys. A 140 ℓ plastic garbage can was connected as an overflow reservoir from the 20 ℓ container. After each rain period with >5 mm, the volume of runoff was recorded. A 100 ml sample was filtered through a 0.45 μ millipore filter system and the dry weight of the suspended solids trapped on the filter was determined. Conductivity of the filtrate was measured with a YSI conductivity meter.

Root Tensile Strength

Fresh roots (<2 mm diameter) of selected species were washed and placed in a rubber holder exposing 5.0 cm of root length. The diameter of the exposed root segment was measured with calipers at the ends and the middle. The holder was attached to an Ametek force gauge and a gradually increasing force was applied along the longitudinal axis of the exposed root until failure. Approximately 75 determinations of tensile strength were made for each specimen. Seeds of *Bromus inermis*, *Coronilla varia*, *Festuca arundinaceae*, *F. rubra*, *Lolium perenne*, *Lotus corniculatus*, *Poa pratensis* and *Populus tremuloides* were planted in red clay soil in boxes 15 cm depth. Except for *P. tremuloides* plants were harvested after seed set had begun.

RESULTS

Vegetation

The vegetation of the transects represents a diverse cross section of the major types present in the Nemadji Basin. Five principle types are apparent: a) Hardwood dominated by *Populus tremuloides*; b) coniferous dominated by *Abies balsamea*; c) mixed hardwood coniferous with varying amounts of *P. tremuloides*, *A. balsamea*, *Betula papyifera*, *Picea glauca*, and *Quercus macrocarpa* and d) grass areas (Table 2a, 3).

The shrub and herb layers accent the diversity of types represented (Table 2b, c).

Soils

Excavations were completed at 35 locations. Two general types were encountered: the Nemadji-Newson Association (Skunk Creek 1, 6 and 12 and Little Balsam 5, 6 and 8) and Ahmeek-Ronneby-Washburn Association (Little Balsam 9 and 10). Results of soil analysis are in Appendix I.

Textural analysis of the Skunk Creek soils reveal a pattern of erosion of the surface soils. The soils at the crest contain a high sand content. Soils downslope have progressively less sand suggesting that on the slope, erosional forces have removed this more mobile fraction of the surface leaving behind the more cohesive clay particles.

Soil chemical properties reflect differences in soil texture and composition and cover. The organic carbon content is characteristicly low except for the grass covered Little Balsam Transect 6 and the fir covered Skunk 12 hole 1 and 2. In general, the sandy soils (Little Balsam 10 and surface soils of Skunk Creek 6 Hole 1 and 2) are low in exchangeable ions measured. For the most part the pH values are suitable for plant uptake of most nutrients. However, the pH of the predominantly clay soils are sufficiently high in some instances to result in a reduced capacity of plants to extract P, K, Fe and Mn from the soils (5, 6). Skunk 12 Hole 1 occurred in a poorly drained table top dominated by fir. Together these features resulted in a very acid soil.

Root Distribution

The mass (Figure 3) and total length (Figure 4) of roots plotted against depth within the soil profile illustrates differences in root distributions related to differences in vegetative cover and soil texture. On similar clay soils tree cover tended to have about twice the root mass as herbaceous cover (Table 4) (Appendix II contains root distribution summary for each excavation site). In addition, the roots from tree cover occur in a relatively steep-sloped log-linear pattern (Table 5) with roughly 50% of the root mass in the 0-10 cm level. The rooting pattern under herbaceous cover declines very steeply with up to 90+% of all roots confined to the 0-10 cm level. Furthermore, the differences in the amounts of roots in the various size class is dramatic between grassed and wooded areas. Generally,

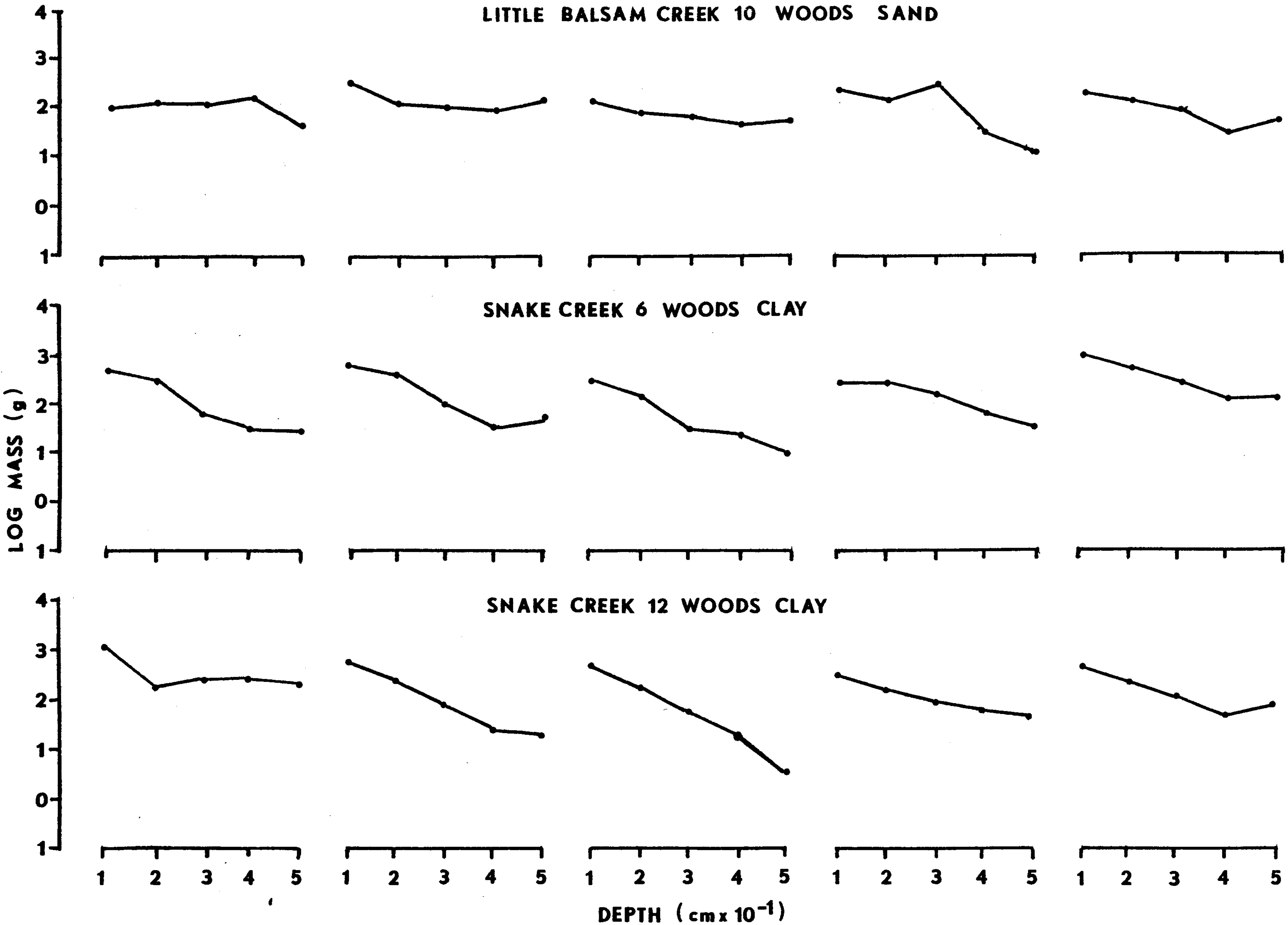

Figure 3. Mass of roots plotted against depth within the soil profile.

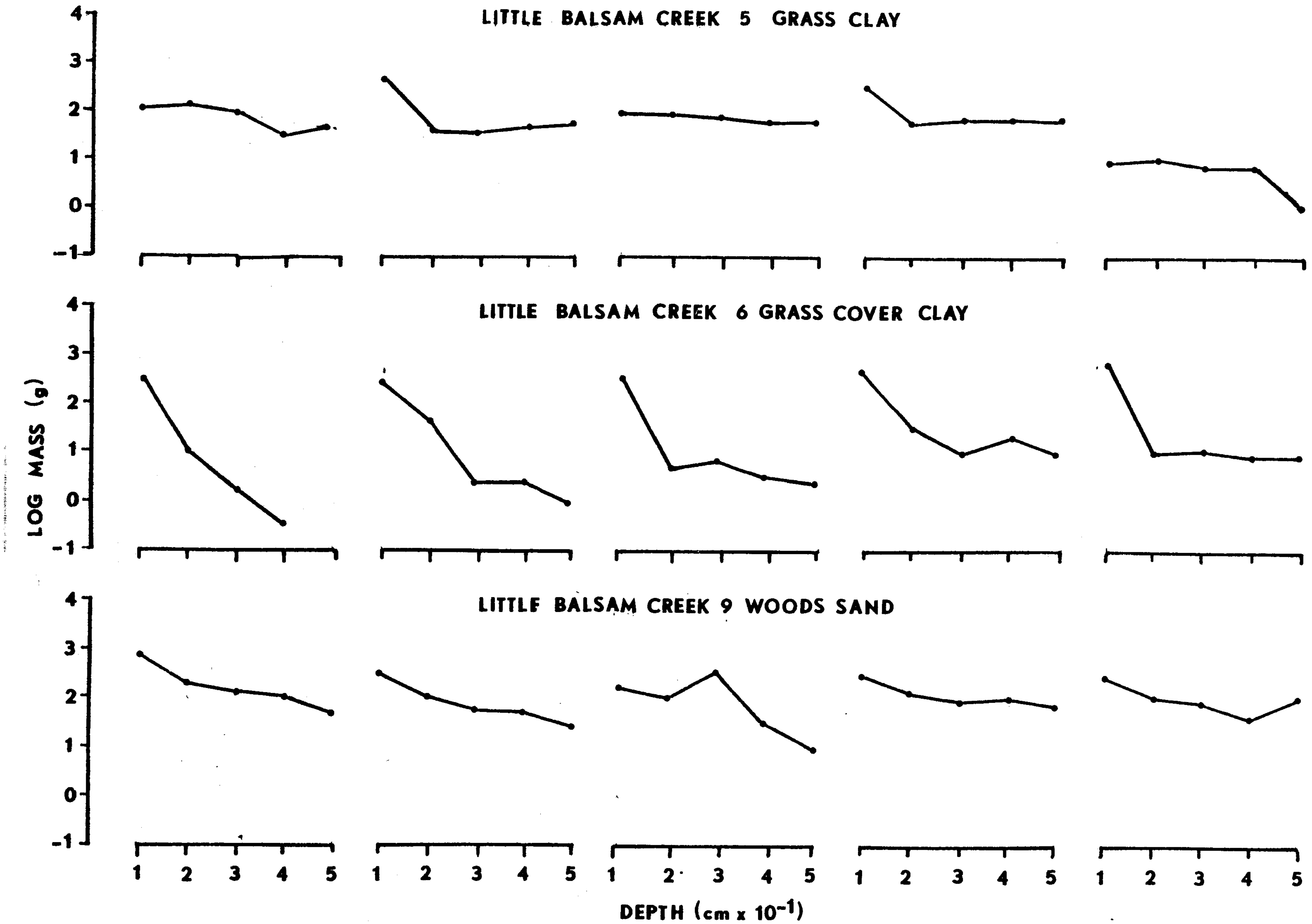

Figure 3. Mass of roots plotted against depth within the soil profile. (continued)

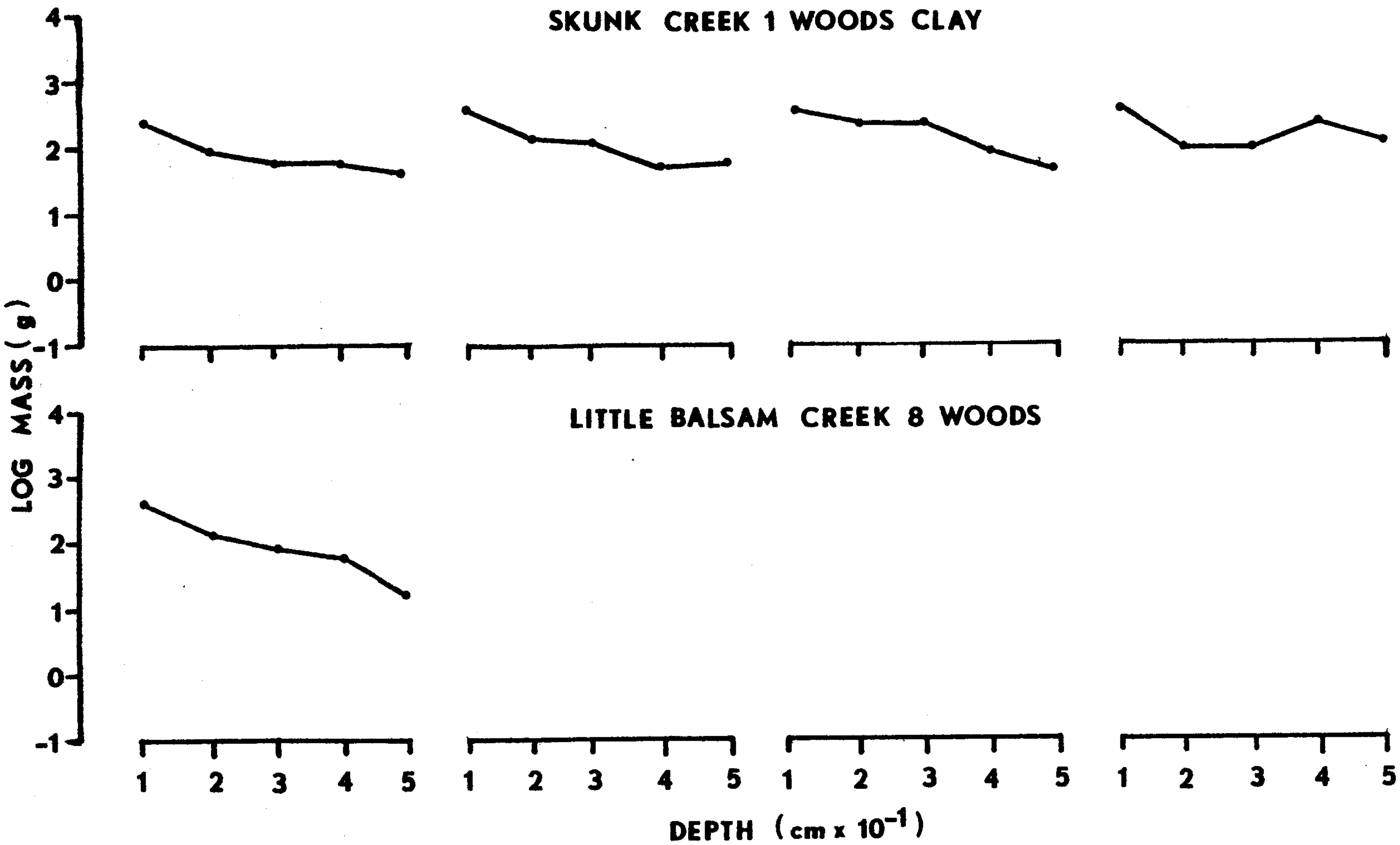

Figure 3. Mass of roots plotted against depth within the soil profile. (continued)

Figure 4. Total length of roots plotted against depth within the soil profile.

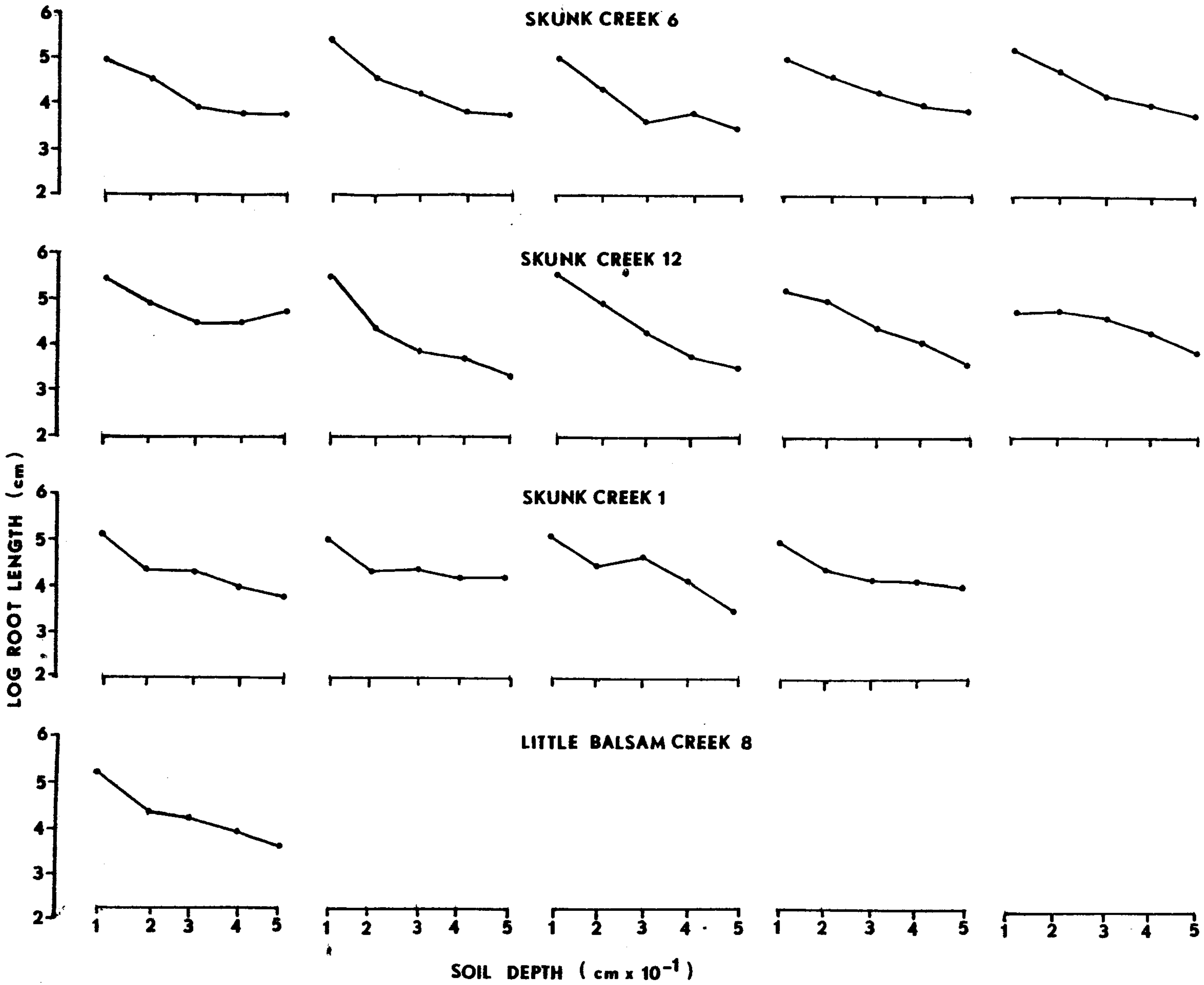

Figure 4. Total length of roots plotted against depth within the soil profile. (continued)

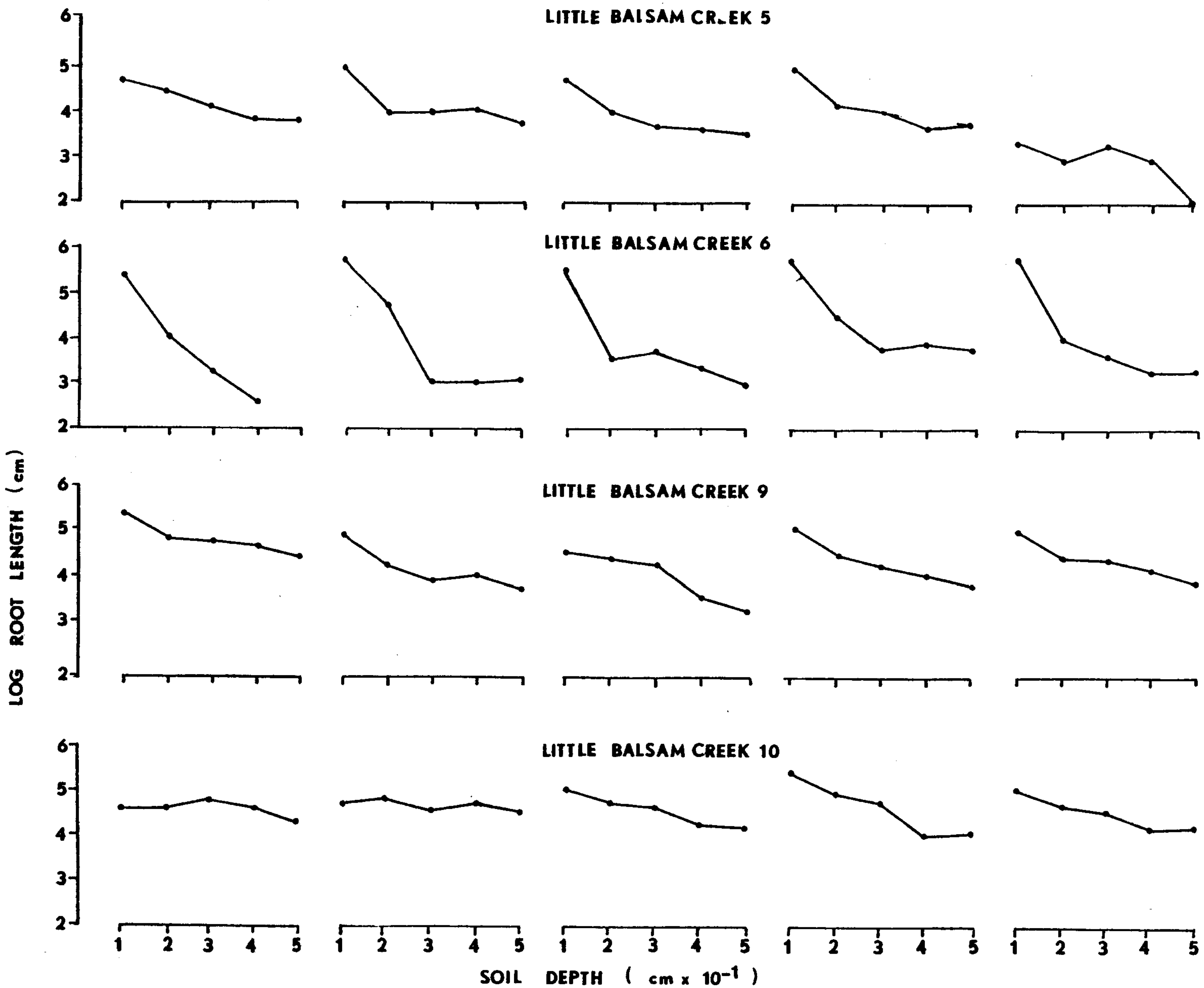

TABLE 2a. Importance percentages of the tree and sapling layer along the slump-transects. (Top number is for trees, bottom number is for saplings.) Little Balsam Transect 1, 2, 5 and 6 were grassy.

	SKUNK CREEK								LITTLE BALSAM CREEK					
	1	2	3	6	8	10	11	12	3	4	7	8	9	10
Abies balsamea Mill.	np 29.2	17.7 np	13.0 np	46.7 58.1	18.8	68.4 84.7	100 33.2	54.8 100.0	5.3 3.8	3.5 13.9			23.5 45.8	22.0 45.0
Acer rubrum L.													3.8 np	8.5 np
A. saccharum Marsh.										12.4 np			4.6 np	3.0 20.9
Betula papyrifera Marsh.			5.4 np	28.2 41.9	5.9	np 8.4		33.2 np	np 10.3		np 13.3		17.7 np	26.5 27.8
Fraxinus pennsylvanica var.				10.0 np					np 16.3	np 11.5				
Ostrya virginiana K. Koch														np 6.3
Picea glauca voss	22.6 np	28.1 np	5.6 np			3.8 6.9		12.0 np	35.0 47.0					
Pinus strobus L.						4.2 np								
Populus balsamifera L.									7.1 np	50.4 20.4				
P. tremuloides Michx.	77.4 62.4	17.0 np	62.5 np	11.3 np	75.4	13.7 np	np 66.8		52.7 7.8	33.8 55.0	100.0 86.7	100.0 100.0	34.2 54.2	26.2 np
Prunus virginiana L.									np 3.7					
Quercus macrocarpa Michx.	np 8.4	37.2 np											16.1 np	3.0 np
Salix sp.									np 5.2					
Tilia americana L.			5.6 np						np 6.0					10.9 np
Ulmus americana L.			7.9 np	3.9 np		9.9 np								

TABLE 3. Classification of vegetation along the 22 transects. (Shrub counts are for 5-25 m^2 quadrats.)

===

Skunk Creek 1. Aspen hardwoods; 191 stems and clumps of shrubs and saplings. P. tremuloides and A. balsamea dominant in shrub layer with Q. macrocarpa also present.

2. Mixture of Q. macrocarpa, A. balsamea, P. tremuloides and P. glauca; shrub layer not sampled.

3. Aspen hardwoods; shrub layer not sampled.

4. No data

5. No data

6. Coniferous, dominated by A. balsamea; 129 stems and clumps of A. balsamea and B. papyrifera dominating the shrub layer.

7. No data.

8. Aspen hardwoods; 216 stems and clumps in the shrub layer.

9. No data

10. Coniferous, A. balsamea; 158 stems and clumps in shrub layer.

11. Sparsely vegetated, the only trees present only at the top of the transect (A. balsamea); 263 stems and clumps, mostly P. tremuloides root sprouts.

12. Coniferous, A. balsamea; 130 stems and clumps in shrub layer.

Little Balsam Creek 1. Pasture with scattered trees and shrubs.

2. Pasture with occasional shrubs.

3. Aspen hardwoods, 161 stems and clumps in shrub layer.

4. Aspen hardwoods with P. balsamea and P. tremuloides; 175 stems and clumps in shrub layer, P. tremuloides dominant in shrub layer.

(continued)

Table 3 (continued)

5. Open grassed area *Phleum pratense*, *Lolium perenne* common.

6. Open grassed area *Phleum pratense* and *L. perenne* common.

7. Aspen hardwoods; 167 stems and clumps in shrub layer.

8. Aspen hardwoods; 219 stems and clumps in shrub layers.

9. Mixed conifer - hardwoods, *P. tremuloides*, *A. balsamea*, and *B. papyrifera* dominate; 141 stems and clumps in shrub layer.

10. Mixed conifer - hardwoods and *B. papyrifera*, *P. tremuloides* and *A. balsamea* dominate; 88 stems and clumps in shrub layer.

TABLE 2b. Importance percentages of the shrub layer along the slump transects. Little Balsam transects 1, 2, 5, and 6 were grassy. In Skunk Creek transects 2, 3, and 12 were not sampled.

	SKUNK CREEK								LITTLE BALSAM CREEK					
	1	2	3	6	8	10	11	12	3	4	7	8	9	10
		None	None					None						
Acer spicatum marsh.				17.64		11.92							8.44	
Alnus rugosa				4.36	16.24	6.48	9.34		12.84	17.01	2.66	4.80	8.44	16.67
Amelanchier sp.	8.14				6.38	10.88	19.54		11.21	2.39	2.56	11.36		16.67
Celastrus scandens	1.42													
Cornus sp.	28.82			14.36	10.78	31.75	15.21		26.66	18.08	42.95	29.94	55.28	
Corylus sp.	13.60			23.09	15.32	6.96	14.12		11.67	40.33	11.34	23.42	23.96	66.67
Crataegus sp.	2.76											1.86		
Diervilla lonicera	14.58			8.36	11.68	9.98	7.46			2.70	2.77			
Lonicera dioica				3.45		3.65	2.42							
Prunus nigra										7.38				
Prunus virginiana	6.00			6.91	13.80	7.1			12.02	9.87			3.89	
Ribes sp.				2.91	3.64	1.72								
Rosa sp.	15.14			2.54	4.40	3.86	6.5		3.20		30.02	13.84		
Rubus parviflora									4.00					
Rubus strigosus											5.16	2.09		
Salix sp.	1.37				2.12		23.21		5.98			7.96		
Vaccinium angustifolium					1.97									
Viburnum sp.	8.16			16.36	13.66	5.72	2.21		12.43	2.24	2.56	4.72		

TABLE 2c. Mass of Standing Crop (a) and Litter (b) From 0.5 m^2 Area From Excavation Sites. Only Those Categories Having >10 g In At Least One Sample are Presented.

		Little Balsam Transect 10					Skunk Creek Transect 6				
Site Number		1	2	3	4	5	1	2	3	4	5
Sampling Date		10 Oct 1975	21 Oct 1975	8 Nov 1975	8 Nov 1975	12 Oct 1976	11 Sep 1975	13 Sep 1975	23 Sep 1975	27 Sep 1975	30 Sep 1975
Populus tremuloides	a	----	----	0.3	----	----	----	----	----	----	----
Michx.	b	37.9	21.8	18.8	20.1	31.0	1.7	3.0	0.9	0.8	0.3
Betula papyrifera	a	----	----	6.7	----	----	----	----	0.4	----	----
Marsh.	b	68.3	14.5	75.0	12.3	83.7	0.9	2.7	5.4	19.5	31.8
Abies Balsamea (L.)	a	----	151.3	----	----	----	0.1	----	0.9	123.4	0.2
Mill.	b	----	----	----	----	----	0.4	----	5.3*	----	----
Quercus borealis	a	----	----	1.0	----	----	----	----	----	5.2	----
Michx.	b	44.4	11.0	2.0	11.0	1.3	----	----	----	----	----
Acer saccharum	a	----	----	----	----	----	----	----	----	----	----
Marsh.	b	32.3	20.2	20.3	15.7	32.6	----	----	----	----	----
Tilia americana L.	a	----	----	----	----	----	----	----	----	----	----
	b	----	----	3.1	18.0	10.7	----	----	----	----	----
Unidentified	a	----	----	544.3	2.6	----	----	----	2.6	8.6	336.5
Woody Stems	b	148.0	233.9	59.7	690.9	135.3	185.5	677.5	143.3	808.2	159.4
Grasses	a	7.4	2.7	----	3.8	----	13.1	2.5	11.2	0.8	2.0
	b	28.2	----	----	3.6	----	3.8	3.7	----	3.1	----
Aster sp.	a	----	----	----	----	----	----	----	----	----	----
	b	4.2	----	----	----	12.1	----	----	----	----	----
Misc.**	a	----	----	----	----	23.2	----	----	----	----	----
	b	268.9	456.5	690.5	336.9	76.3	460.1	486.6	705.0	427.5	484.9
Total	a	7.4	161.9	554.2	6.9	23.2	19.8	4.0	141.8	314.6	339.5
	b	623.2	772.2	869.4	1138.5	414.0	652.4	1173.9	736.7	1098.7	676.5

* Cones
** Includes bryophytes attached to small branches.

(continued)

Table 2c (continued)

Site Number		Little Balsam Transect 5: 1	2	3	4	5
Sampling Date		9 June 1976	9 July 1976	10 July 1976	11 July 1976	8 July 1976
Grass	a	9.6	55.8	15.5	23.4	4.2
	b	----	----	----	----	----
Solidago sp.	a	1.7	25.6	1.3	13.7	0.6
	b	----	----	6.8	----	----
Misc.	a	18.5	18.1	3.1	2.0	0.4
	b	165.7	201.3	46.4	113.4	----
Total	a	29.8	99.5	19.9	39.1	5.2
	b	165.7	201.3	53.2	113.4	----

Site Number		Little Balsam Transect 6: 1	2	3	4	5
Sampling Date		12 July 1976	12 July 1976	3 Aug 1976	18 Aug 1976	18 Aug 1976
Solidago sp.	a	16.8	14.0	30.6	----	----
	b	----	----	----	----	----
Grass	a	16.2	21.2	22.3	45.5	41.6
	b	----	88.7	69.4	58.0	75.0
Fragaria sp.	a	----	7.5	6.9	----	12.3
	b	----	----	----	----	----
Umbelliferae	a	27.3	----	----	----	----
	b	----	----	----	----	----
Trifolium sp.	a	----	13.2	5.8	124.0	5.2
	b	----	----	----	----	----
Aster sp.	a	----	11.7	3.3	8.5	----
	b	----	----	----	----	----
Misc.	a	27.4	21.6	19.0	42.9	22.2
	b	228.7	22.0	12.8	----	----
Total	a	87.7	89.2	87.9	220.9	98.5
	b	228.7	110.7	82.2	58.0	75.0

(continued)

Table 2c (continued)

Site Number		Skunk Creek Transect 12 1	2	3	4	5
Betula papyrifera Marsh.	a	----	----	----	----	----
	b	56.7	31.9	0.9	1.3	----
Populus tremuloides Michx.	a	----	55.5	----	----	----
	b	1.4	----	----	----	0.1
Moss	a	----	87.5	44.4	11.4	340.0
	b	----	----	----	----	----
Carex sp.	a	10.3	----	----	----	1.9
	b	----	----	----	----	----
Aster sp.	a	----	----	20.2	----	0.7
	b	----	----	----	----	----
Picea glauca (Moench) Voss	a	----	1.6	----	----	----
	b	----	----	29.4	19.7	3.9 (cones)
Equisetum sp.	a	----	----	----	12.5	0.6
	b	----	----	----	----	----
Corylus sp.	a	----	----	----	25.6	----
	b	----	----	----	----	----
Abies balsamea (L.) Mill.	a	----	0.1	----	----	12.4
	b	2.6	----	----	----	----
Cornus sp.	a	----	----	----	332.0	----
	b	----	----	----	----	----
Fraxinus sp.	a	----	----	----	----	602.7
	b	----	----	----	----	----
Miscellaneous	a	----	----	48.1	31.0	78.6
	b	874.4	1555.1	2086.1	1005.9	127.0
Total	a	10.3	200.2	76.1	423.9	1036.9
	b	944.0	1587.0	2116.4	1026.9	131.0

(continued)

Table 2c (continued)

Site Number		Skunk Creek Transect 1			
		1	2	3	4
Rosa sp.	a	20.0	5.9	----	----
	b	4.2	----	----	----
Crataegus sp.	a	43.1	----	----	----
	b	11.1	----	----	----
Diervilla lonicera Mill.	a	35.5	1.6	1.8	19.5
	b	----	----	----	----
Fragaria sp.	a	13.7	2.2	0.9	0.4
	b	2.2	----	0.5	----
Carex sp.	a	27.1	54.9	----	37.8
	b	----	----	----	----
Populus tremuloides Michx.	a	----	----	----	----
	b	37.2	93.8	31.6	127.5
Viburnum sp.	a	----	43.6	0.2	----
	b	----	----	----	----
Amelanchier sp.	a	----	73.9	----	----
	b	----	----	----	----
Cornus sp.	a	1.1	270.4	229.9	7.6
	b	----	----	----	----
Grass	a	----	----	72.9	----
	b	----	6.6	8.8	----
Miscellaneous	a	31.9	0.2	----	10.5
	b	235.1	135.0	639.6	794.0
Betula papyrifera Marsh. (Bark)	a	----	----	----	----
	b	----	----	----	79.1
Total	a	172.4	452.7	305.7	75.8
	b	289.8	235.4	680.5	1000.6

(continued)

Table 2c (continued)

Site Number		Little Balsam Transect 9 1	2	3	4	5
Cornus sp.	a	1.0	10.7	147.7	46.2	89.7
	b	----	----	34.6	----	----
Aster sp.	a	3.1	3.3	----	----	1.0
	b	----	----	10.0	----	----
Quercus borealis Michx.	a	----	----	----	----	----
	b	2.1	13.1	113.9	50.9	47.1
Acer saccharum Marsh	a	0.7	0.1	----	----	----
	b	25.0	1.4	41.3	----	6.0
Populus tremuloides Michx.	a	----	----	----	----	----
	b	41.4	15.4	36.9	19.3	11.4
Miscellaneous	a	34.2	3.4	5.6	----	----
	b	2280.6	437.7	542.5	284.0	134.7
Carex sp.	a	----	----	----	11.9	6.6
	b	----	----	----	----	0.9
Moss	a	----	----	----	----	78.2
	b	----	----	----	----	----
Total	a	39.0	17.5	153.3		
	b	2349.1	467.6	779.2		

Site Number		Little Balsam Transect 8 1
Aster sp.	a	27.8
	b	----
Cornus sp.	a	140.6
	b	----
Populus tremuloides Michx.	a	----
	b	48.5
Miscellaneous	a	10.8
	b	80.7
Total	a	179.2
	b	----

in the wooded areas, the <0.5 mm category constitutes 15-22% of the total root mass. As root diameters increase, the mass gradually diminishes per size class. In the predominantly grass covered Balsam 6, approximately 60% of the root mass is in the <0.5 mm size class. The remainder of the root mass is distributed nearly uniformly among the 4 size classes between 0.5 and 5.0 mm. The composition of the 2 herbaceous cover transects is quite different in both quantity and type of plants. Little Balsam 5 was sparsely vegetated and had considerable amounts of *Equisetum* rhizomes occurring uniformly throughout the 50 cm profile. In the sandy soils roots tended toward a gently sloping log-linear distribution (Table 4, 5) but with a greater variance than in the clay soils. From field observations it was apparent that 50 cm depth was sufficient to recover essentially all roots in the clay soils. However, in the sandy soils the roots penetrate to much greater depths.

Table 4. Summary of root distribution data.

	Total Root Mass $\bar{X} \pm S_{\bar{x}}$	Mean Percentage of Total Root Mass in 0-10 cm	Mean Percentage of Total Root Mass in 10-20 cm
Herbaceous Cover - Clay			
Little Balsam 5	446 ± 108	39	21
Little Balsam 6	578 ± 80	93	4
Combined	512 ± 67	66	13
Tree Cover - Stand			
Little Balsam 9	872 ± 88	44	18
Little Balsam 10	660 ± 83	34	21
Combined	766 ± 67	39	20
Tree Cover - Clay			
Little Balsam 8	719	58	18
Skunk 1	824 ± 99	43	18
Skunk 6	1293 ± 382	50	30
Skunk 12	1277 ± 256	57	20
Combined	1124 ± 156	51	23

TABLE 5. Regression analysis of root distribution patterns on total mass and total length of roots at each 10 cm layer. The form Y = a + bx where Y = log root mass or log root length and X = soil layer (cm x 10^{-1}).

Transect	Hole	Mass r	Mass a	Mass b	Length r	Length a	Length b
Balsam 5		Not log-linear function					
Balsam 6		Not log-linear function					
Balsam 8	1)	-0.970	2.8730	-0.3091	-0.946	5.3662	-0.3430
Balsam 9	1)	-0.966	2.9832	-0.2544	-0.920	5.4570	-0.2012
	2)	-0.963	2.7137	-0.2419	-0.877	4.9628	-0.2466
	3)	-0.792	2.9082	-0.3163	-0.961	5.1389	-0.3528
	4)	-0.858	2.5427	-0.1114	-0.963	5.2633	-0.2859
	5)	-0.737	2.4824	-0.1325	-0.955	5.2228	-0.2504
Balsam 10	1)	-0.347	2.1356	-0.0407	-0.481	4.6083	-0.0522
	2)	-0.437	2.3190	-0.0578	-0.777	4.7186	-0.0479
	3)	-0.893	2.2686	-0.1192	-0.981	5.0519	-0.2064
	4)	-0.847	2.9931	-0.3277	-0.955	5.5751	-0.3499
	5)	-0.912	2.5667	-0.1792	-0.971	5.0763	-0.2118
Skunk 1	1)	-0.936	2.5196	-0.1972	-0.932	5.2969	-0.3122
	2)	-0.941	2.7014	-0.2025	-0.845	5.0086	-0.1863
	3)	-0.953	2.8490	-0.2167	-0.937	5.4467	-0.3658
	4)	0.400	2.4045	-0.0697	-0.894	4.9843	-0.2335
Skunk 6	1)	-0.966	3.0298	-0.3438	-0.937	5.3163	-0.3344
	2)	-0.930	3.1163	-0.302	-0.949	5.6678	-0.3892
	3)	-0.973	2.8498	-0.3635	-0.910	5.2394	-0.3608
	4)	-0.974	2.8508	-0.2431	-0.965	5.3337	-0.2779
	5)	-0.970	3.3426	-0.2563	-0.972	5.5953	-0.3688
Skunk 10	1)	-0.600	2.9017	-0.1159	-0.716	5.3160	-0.1655
	2)	-0.984	3.1984	-0.4046	-0.945	5.6718	-0.5001
	3)	-0.997	3.4321	-0.5440	-0.988	5.9978	-0.5185
	4)	-0.989	2.7976	-0.2302	-0.992	5.7302	-0.4175
	5)	-0.880	2.8447	-0.2089	-0.926	5.1718	-0.2275

The general pattern of root distributions for herbs in the field was also apparent for plants grown in clay in the greenhouse. Between 50% and 85% of the total root mass was confined to the upper 10 cm of soil.

Among the species commonly used to stabilize roadsides *L. perenne* and *F. arundinacea* produced the greatest above ground phytomass and had 20-25% of their total phytomass as roots and rhizomes (Table 6). C. varia provided a relatively good amount of root but this occurred primarily as a thick tap root. Thus the amount of soil reinforcement is less than for plants with a more diffuse pattern for a similar amount of root mass, (e.g. P. tremuloides Table 6).

Table 6. Summary of phytomass production of selected species in red clay soil.

	Above Ground Phytomass (g)	Below Ground Phytomass (g)	Ratio
Bromus inermis	70.3	66.0	1.07
Coronilla varia	33.3-70.0	39.6-81.7	0.85
Festuca arundinacea	246.0-258.4	74.3-75.3	3.37
F. rubra	68.8	8.6	8.0
Lolium perenne	213-215	40.8-79.0	3.98
Lotus corniculatus	34.4-96.4	15.8-23.5	3.14
Poa pratensis	51.7-66.9	8.3-10.8	6.21
Populus tremuloides	16.1-42.0	39.0-81	0.46

Root Tensile Strength

Measures of root tensile strength show major differences among woody and herbaceous species (Table 7). The strength of small roots (1 mm diam.) of woody plants were 1.5-8.5 x stronger than of herbaceous plants generally used in roadside stabilization.

The tensile strength of small roots of deciduous woody species may be correlated with the strength of wood as measured by the modulus of repture. Wells (7) demonstrated a relationship among numerous morphological features and the successional position of species in the Eastern Deciduous Forest Complex. The modulus of rupture was significantly, positively correlated with advancing successional development. Representative values of the modulus of rupture (K Pa) for major taxa in our area are: willow, 33,00; aspen, 35,000; black ash, 41,000; paper birch, 44,000; American elm, 50,000; red maple, 53,000; northern red oak, 57,000; sugar maple, 57,000; balsam fir, 34,000; white spruce, 37,000; and white pine, 34,000 (8). If the relationship between root tensile strength and the modulus of rupture is widespread, then the more advanced successional species can be expected to have the greatest per-unit root strength. Our measures of root strength show red maple to be substantially stronger than aspen in nearly the same proportions as the modulus of rupture would suggest (Table 7). The conifers do not seem to follow this pattern. Balsam fir, white spruce and white pines exhibit a range of root tensile strength (Table 7) while the modulus of rupture for these taxa are similar.

Table 7. Summary of root tensile strength measures.

Species	# of specimens	r^2	Tensile strength of roots[1] 0.1 cm diam.	Tensile strength of roots[1] 0.79 cm diam.
Alnus rugosa Spreng.	1	0.69	1.2	30.8
Populus tremuloides Michx.	7	0.86-0.96	1.2	50.9
Cornus sp.	1	0.90	1.7	69.9
Corylus cornuta Marsh.	2	0.80-0.94	1.8	219.4
Acer spicatum Lam.	3	0.94-0.96	2.0	198.7
Acer rubrum L.	1	0.93	3.4	715.9
Abies balsamea Mill.	4	0.88-0.97	1.2	98.0
Picea glauca Voss.	5	0.90-0.93	1.2	55.9
Pinus strobus L.	1	0.88	1.3	71.5
Bromus inermis Leyss	1	0.70	0.5	nd
Coronilla varia L.	1	0.72	0.6	nd
Lolium perenne L.	1	0.20	0.4	nd
Festuca rubra L.	1	0.72	0.9	nd
Lotus corniculatus L.	1	0.22	0.5	nd
Poa pratensis L.	1	0.79	0.6	nd

[1]Estimates derived from linear regression analysis.

Soil Slumping

From the time of installation of the stakes, 7 seasonal intervals over the 34 month period were observed: I, August 1975-November 1975; II, November 1975-April 1976; III, April 1976-October 1976; IV, October 1976-May 1977; V, May 1977-

August 1977; VI, August 1977-November 1977; VII, November 1977-June 1978. The summary of slumping as determined from between-stake measurements indicates considerably more slumping activity occurred during period II and VII than the other five periods. This is apparent in the number of transect intervals exhibiting displacement, the magnitude of individual displacements (both maximum and $\Sigma|\text{displacements}|$) and the net displacement along the transect (Table 8). During period II all 22 transects had net displacements of $>|0.10|$ ft. In period VII all of the Skunk Creek sites and three of the Little Balsam sites had displacement >0.10 ft. Periods I, II, IV, V and VI had 6, 14, 16, 4 transects with $>|0.10|$ ft. respectively.

Significant soil movement occurred over the 34 month period (Table 8) with a maximum transect elongation of 6.64 ft in Skunk Creek 11, 3.46 ft in Little Balsam Creek 8. Seven other transects had >1 foot elongation. In addition, Skunk Creek 11 and Little Balsam Creek 8 lost a total of 5.0 and 9.5 ft of stream bank during spring floods of 1976, 1977 and 1978.

Three general types of soil movement are apparent in the data: 1, overall elongation of the transect (positive displacements); 2, overall compression of the transect (negative displacements resulting from the crest settling); 3, combinations of positive and negative displacements relating to the ridge top (Figure 5).

During the periods of higher activity most of the movement lead to a general elongation of transect while periods of lesser activity tended to have both positive and negative displacements. It is likely that both types were present even in the periods of high activity but were masked by a general downward slippage.

Although the influence of freeze-thaw is generally considered to be a major stimulus to trigger slumping, our data would suggest that soil moisture conditions may be equally critical. Our maximum activity occurred in the springs of 1976 and 1978. In both periods the soils were at or near saturation. The soils in the spring of 1977 were quite dry and there was relatively little slumping.

Although several factors interact to effect erosion, the type of cover appears to be closely related to the magnitudes of slumping. The maximum developments occurred in Skunk Creek Transect 11 which is treeless, Little Balsam 6, a grassed slope and Little Balsam 8, a sparsely covered aspen area. Aspen covered sites exhibited a wide range of erosion activity. Generally, the moderately dense aspen areas having an understory with *Corylus* sp. appeared to be more stable than stands with a less developed shrub layer. The mixed conifer-hardwood stands also appear to be correlated with greater stability.

TABLE 8. Little Balsam Creek and Skunk Creek Transect Summaries

Transect	Transect Length August 1975	Intervals	Number Intervals With Measurable Displacement: Period I	II	III	IV	V	VI	VII	Total
Little Balsam										
1	256.57	9	5	8	6	4	1	--	5	8
2	347.05	6	6	6	5	3	1	--	2	6
3	363.17	6	4	4	4	1	3	--	--	6
4	82.63	4	2	4	2	2	0	--	0	3
5	119.54	5	0	5	5	5	3	1	2	4
6	263.10	10	5	10	6	8	5	4	5	10
7	151.55	6	3	6	6	3	5	--	4	6
8	128.36	8	5	7	4	4	6	--	5	8
9	137.51	5	3	5	2	0	1	--	1	5
10	111.85	5	0	5	1	1	2	0	0	5
Skunk										
1	314.42	9	3	9	3	4	5	--	7	9
2	197.84	9	4	8	7	4	5	--	6	8
3	175.48	7	3	7	2	5	0	--	4	7
4	171.08	9	5	9	7	5	2	--	7	9
5	121.45	7	5	7	5	4	4	--	5	6
6	318.06	7	5	6	6	4	3	--	--	7
7	299.93	13	8	13	5	4	3	--	10	11
8	132.50	3	2	3	2	0	0	--	--	3
9	137.53	9	6	8	5	7	1	--	7	8
10	122.41	5	0	5	2	3	0	--	3	4
11	130.14	8	5	8	2	8	6	--	8	8
12	232.97	9	4	9	5	6	3	--	7	9

Transect	Maximum Displacement: Period I	II	III	IV	V	VI	VII	Total
Little Balsam								
1	-0.10	0.12	-0.06	0.07	0.03	--	±0.05	0.22
2	-0.56	0.10	0.10	-0.20	0.04	--	0.03	-0.53
3	-0.20	-0.08	-0.38	0.05	0.61	--	--	0.42
4	-0.05	0.12	-0.18	0.11	0.00	--	0.00	0.13
5	0.00	0.11	0.19	-0.12	-0.09	-0.03	0.03	0.21
6	-0.08	0.33	0.36	-0.34	0.18	0.10	0.34	0.75
7	0.05	0.16	0.07	-0.07	±0.03	--	0.10	0.31
8	0.65	1.54	0.06	0.12	-0.11	--	0.16	1.66
9	0.06	0.11	±0.05	0.00	0.04	--	0.03	0.12
10	0.00	0.18	-0.17	0.11	0.05	0.00	0.00	0.13
Skunk								
1	0.06	0.55	-0.35	-0.19	0.09	--	0.13	0.22
2	0.04	0.22	0.10	-0.09	0.10	--	0.10	0.22
3	0.05	0.10	0.06	-0.06	0.00	--	0.16	0.20
4	0.10	0.13	-0.10	0.10	-0.05	--	0.12	0.19
5	0.07	0.03	0.14	-0.08	-0.09	--	0.21	0.39
6	0.27	-0.13	0.29	-0.24	-0.15	--	--	0.19
7	0.03	0.21	-0.07	0.34	0.60	--	-0.28	0.80
8	0.04	0.14	-0.07	0.00	0.00	--	--	0.10
9	±0.04	0.17	0.10	0.36	-0.06	--	0.57	-0.52
10	0.00	0.09	0.04	-0.05	0.00	--	0.11	0.21
11	-0.10	0.31	0.19	-0.23	0.26	--	2.26	2.32
12	-0.08	0.12	±0.05	-0.19	-0.13	--	-0.94	-1.30

(continued)

Table 8 (continued)

Transect	Net Displacement Period I	II	III	IV	V	VI	VII	Total
Little Balsam								
1	-0.21	0.78	-0.19	0.24	0.03	--	0.00	0.73
2	-0.47	0.31	0.13	0.36	0.04	--	0.06	-0.10
3	-0.06	0.10	-0.03	0.05	1.14	--	--	1.22
4	-0.05	-0.39	-0.25	0.16	0.00	--	0.04	0.29
5	0.00	0.27	0.46	0.38	0.00	-0.03	0.06	0.45
6	-0.12	1.36	0.29	0.81	0.35	0.19	0.60	2.64
7	0.09	0.69	0.00	0.13	0.00	--	0.25	0.99
8	0.63	2.18	0.00	0.30	-0.08	--	0.42	3.46
9	0.05	0.38	0.00	0.00	0.04	--	0.00	0.39
10	0.03	0.48	-0.17	0.11	0.09	0.00	0.00	0.44
Skunk								
1	-0.05	1.22	-0.13	-0.14	0.06	--	0.45	1.13
2	0.00	0.66	-0.14	-0.11	0.00	--	0.20	0.99
3	0.08	0.56	0.10	-0.13	0.00	--	0.15	0.83
4	0.14	0.71	-0.03	-0.00	0.00	--	0.24	1.07
5	0.06	0.83	-0.14	-0.11	-0.08	--	0.40	1.03
6	0.62	0.11	0.42	-0.29	-0.25	--	--	0.70
7	0.15	1.30	0.00	0.27	0.08	--	-0.13	1.60
8	0.00	0.34	-0.12	0.00	0.00	--	--	0.21
9	0.07	0.55	0.12	-0.13	-0.06	--	0.94	1.45
10	0.00	0.42	0.00	0.00	0.00	--	0.11	0.55
11	0.00	0.99	0.19	0.35	0.33	--	4.76	6.64
12	0.04	0.60	0.09	0.08	0.06	--	-0.39	0.49

Transect	Σ | Displacement | Period I	II	III	IV	V	VI	VII	Total
Little Balsam								
1	0.35	0.78	0.25	0.24	0.03	--	0.19	0.93
2	0.83	0.47	0.26	0.36	0.04	--	0.06	1.10
3	0.47	0.24	0.87	0.05	1.14	--	--	1.12
4	0.09	0.39	0.25	0.16	0.00	--	0.00	0.29
5	0.00	0.35	0.46	0.38	0.18	0.03	0.06	0.45
6	0.20	1.36	0.57	0.81	0.35	0.19	0.71	2.70
7	0.10	0.69	0.36	0.13	0.20	--	0.27	0.99
8	0.91	2.19	0.17	0.30	0.38	--	0.45	3.58
9	0.13	0.38	0.10	0.00	0.04	--	0.03	0.39
10	0.00	0.48	0.17	0.11	0.09	0.00	0.00	0.44
Skunk								
1	0.16	1.22	0.43	0.32	0.28	--	0.45	1.13
2	0.13	0.81	0.36	0.23	0.26	--	0.40	1.09
3	0.11	0.56	0.10	0.21	0.00	--	0.35	0.83
4	0.24	0.71	0.35	0.28	0.09	--	0.39	1.07
5	0.20	0.83	0.27	0.17	0.24	--	0.44	1.03
6	0.60	0.43	0.62	0.61	0.25	--	--	0.70
7	0.20	1.30	0.18	0.53	0.14	--	0.97	2.44
8	0.07	0.34	0.12	0.00	0.00	--	--	0.21
9	0.20	0.88	0.34	0.97	0.06	--	1.90	2.89
10	0.00	0.42	0.07	0.12	0.00	--	0.22	0.55
11	0.22	1.03	0.21	1.03	0.61	--	5.54	7.56
12	0.18	0.74	0.19	0.70	0.32	--	1.96	3.67

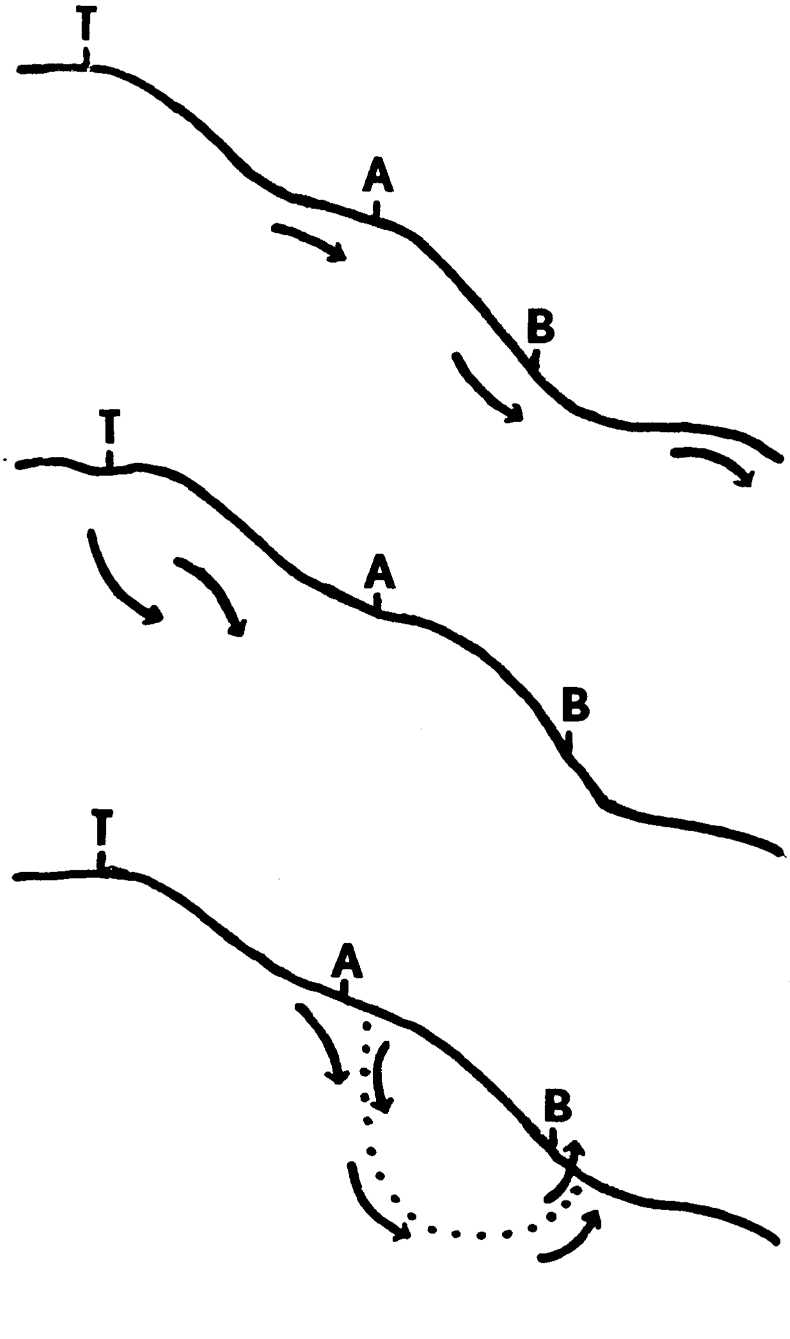

Figure 5 : Scheme of three types of slumping activity to account for: 1) elongation of the transect, 2) compression of the transect and 3) coupled internal positive and negative displacements, i.e. rotational slumping.

Surface Runoff

Following the installation of the surface runoff enclosures a total of 29 rain periods were monitored during late summer 1976 and summer 1977. Our system was not suited to handle the spring melt runoff. Consequently, the runoff and sediment values we report are applicable for summer conditions only.

The volume of runoff in areas with slumping was considerably higher than in stable areas for both grassed and wooded areas (Figures 6, and 7; Table 9) and tended to increase logarithmically with increasing amounts of rainfall. In both grassed and wooded areas, the amount of runoff from the stable soils appears relatively high in the >60 mm category. This may be due to circumstances as only 3 rains of this magnitude were recorded and 2 occurred after the soil surface had frozen and leaf fall had begun. Otherwise the volume of runoff between the wooded and grassed areas is remarkably similar.

The sediment load was extremely variable, especially in the grassed areas (Figures 8 and 9). Again major differences are apparent between the slumped and stable areas. The major difference occurred between the grassed and the wooded areas with approximately 10-20-fold or more sediment in the runoff from the grassed areas. The estimated soil loss ($mton \cdot ha^{-1}$) during the period 25 June - 4 October 1976 are: stable grass, 0.011; slumped grass, 1.727; and slumped woods, 0.225. During the period 15 May - 15 October 1977 the soil loss was: stable grass, 0.215; slumped grass, 7.838; stable woods, 0.036; slumped woods, 0.387.

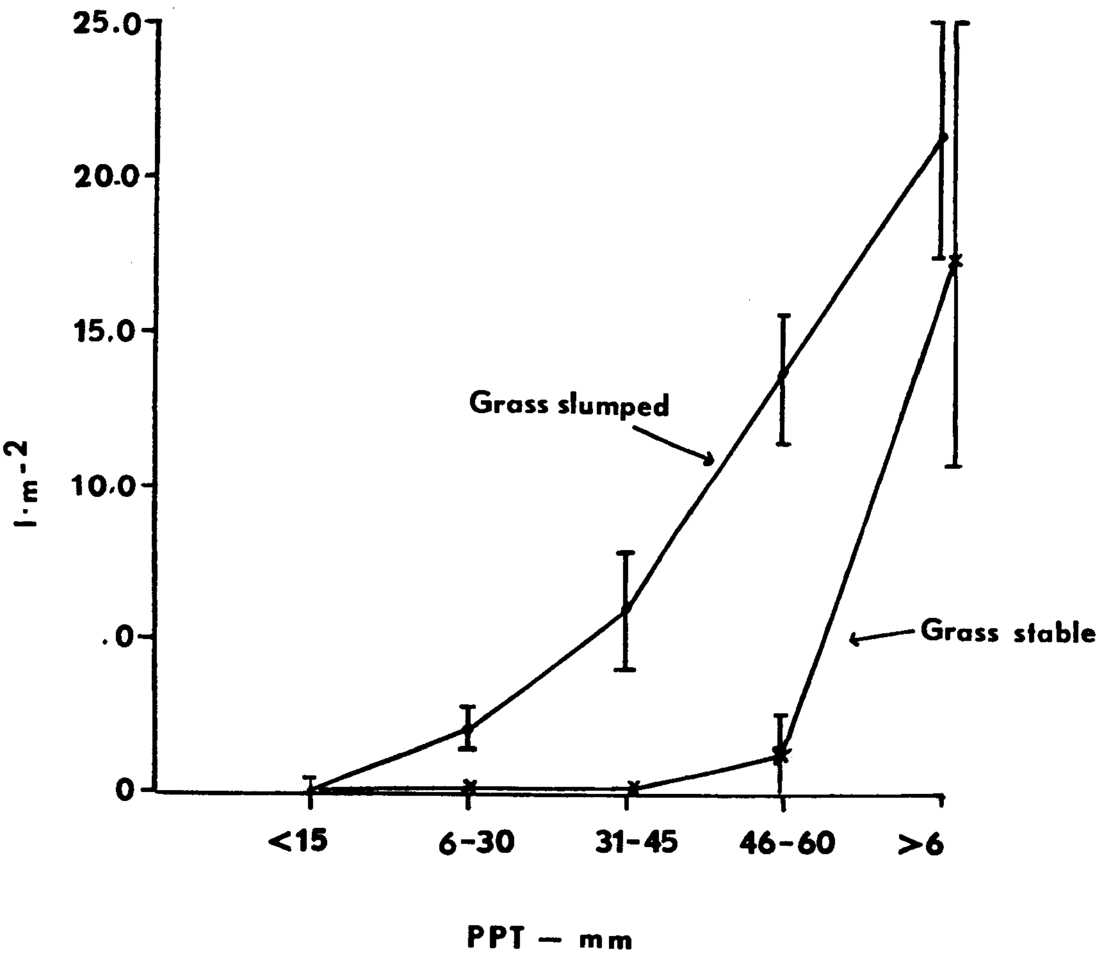

Figure 6. Mean Surface Runoff of Grassed Areas.

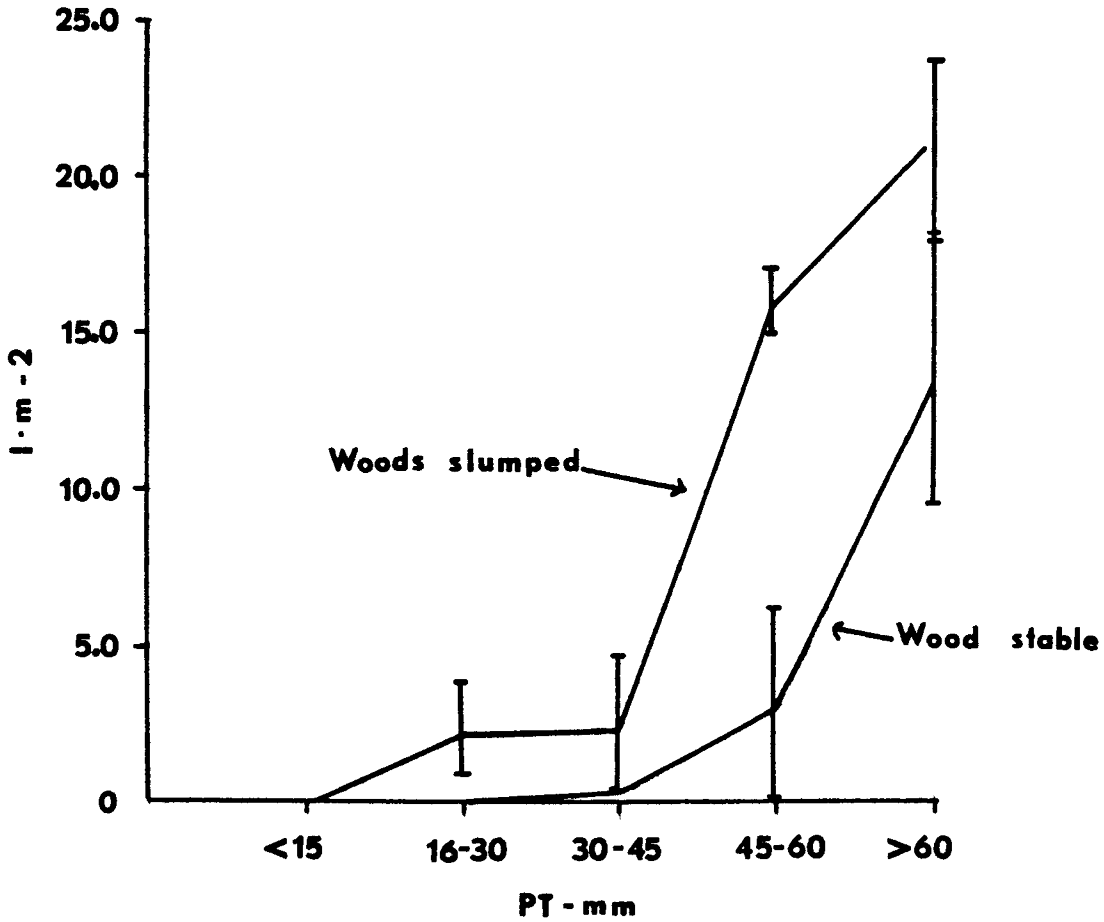

Figure 7. Mean Runoff of Wooded Areas.

TABLE 9. Summary of surface runoff data for 1976 and 1977. The amount of rainfall during the monitoring periods for 1976 in 8 rain periods was 162 mm and for 1977 in 21 rain periods was 682 mm.

	% Slope[1,2]	% Cover[1,3]	Total Runoff ($\ell \cdot m^{-2}$)		Total Sediment ($g \cdot m^{-2}$)		Conductivity[1] (µmhos)	
			1976	1977	1976	1977	1976	1977
Grass								
Stable	21.48 ± 1.65	95 ± 4	0.97	58.25	1.1464	21.5376	96 ± 19	202 ± 15
Slumped	16.06 ± 1.20	26 ± 13	44.63	122.09	172.7176	783.7914	173 ± 16	195 ± 16
Woods								
Stable	16.90 ± 2.13	94 ± 5	nd	47.04	nd	3.6393	nd	144 ± 37
Slumped	30.78 ± 2.80	18 ± 4	13.08	121.93	22.4816	38.6715	178 ± 10	220 ± 30

[1]Values are $\overline{X} \pm S_x$ for the 5 replicate plots.

[2]Visual estimate includes litter, lichens and bryophytes.

[3]Determined from 3 slope measures in the upper half of the enclosure and 3 in the lower half of the enclosure.

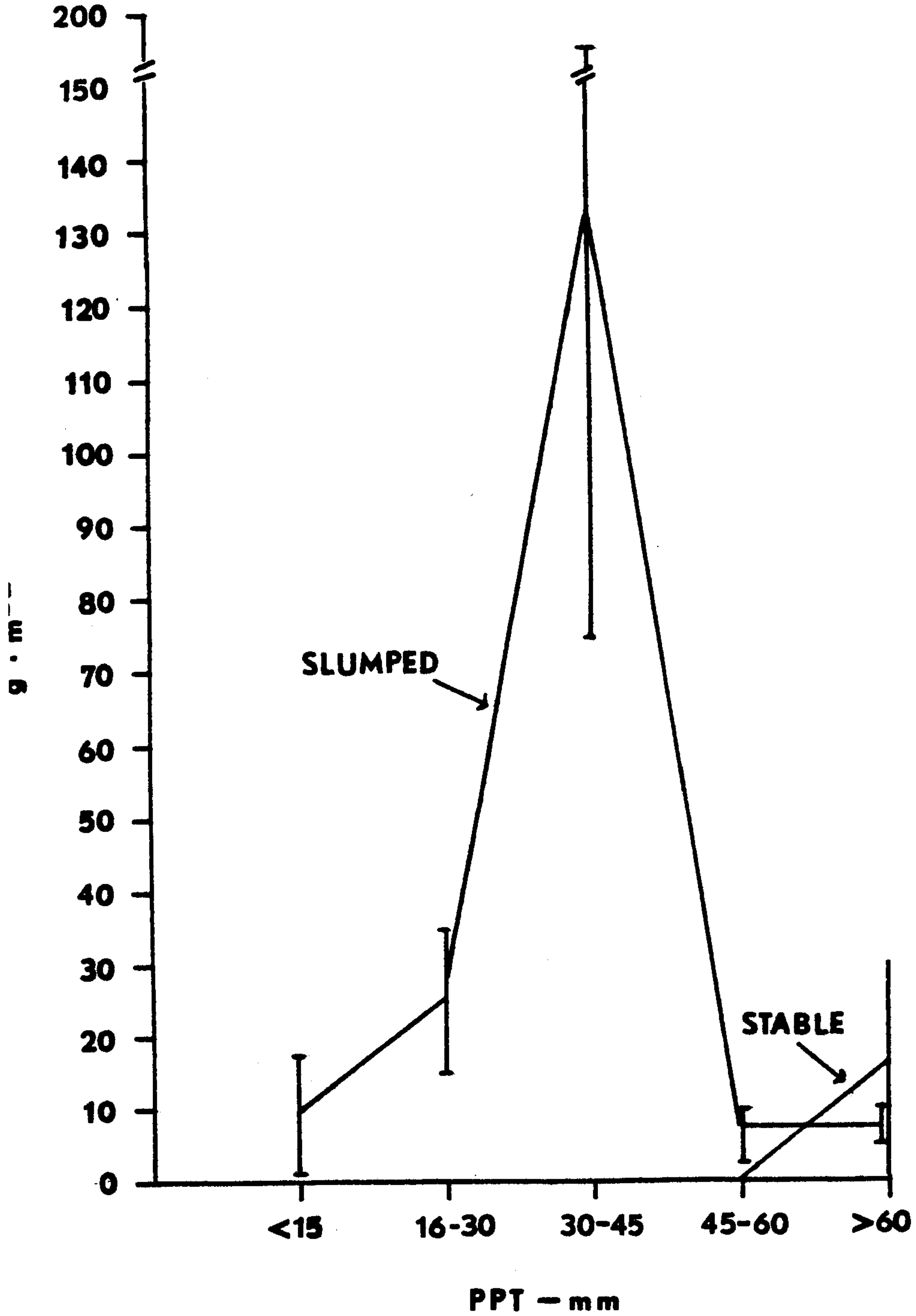

Figure 8. Mean Sediment Load of Grassed Areas.

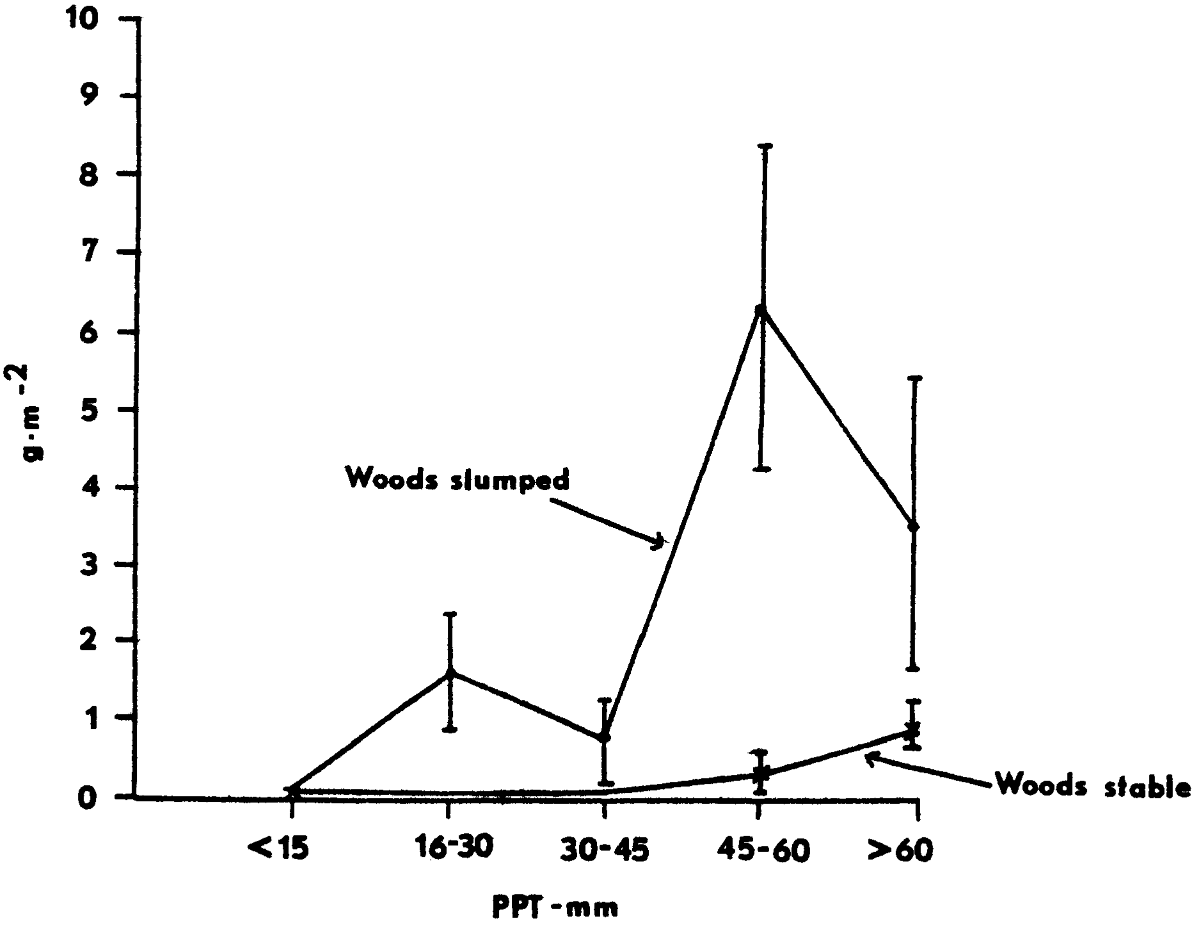

Figure 9. Mean Sediment Load of Wooded Areas.

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APPENDIX I

A. Textural analysis of soils from 5 depths from 5 plots along Skunk Creek Transects 1, 6, 12 and Little Balsam Creek Transects 5, 6, 8, 9, 10. The holes are positioned sequentially from the hill crest (Hole 1) to the stream bank (Hole 5).

Location and Depth (cm)		SKUNK CREEK TRANSECT 1 % Sand	% Silt	% Clay	Soil Type	SKUNK CREEK TRANSECT 6 % Sand	% Silt	% Clay	Soil Type
Hole 1	0-10	22	24	54	clay	64	8	28	sandy clay loam
	10-20	12	22	64	clay	73	3	24	sandy clay loam
	20-30	10	24	66	clay	15	5	80	clay
	30-40	10	26	64	clay	1	11	88	clay
	40-50	14	26	60	clay	4	12	84	clay
Hole 2	0-10	22	9	79	clay	60	8	32	sandy clay loam
	10-20	6	22	72	clay	46	14	40	sandy clay
	20-30	8	18	74	clay	61	5	34	sandy clay loam
	30-40	4	18	78	clay	60	6	34	sandy clay loam
	40-50	0	14	86	clay	15	7	78	clay
Hole 3	0-10	22	21	57	clay	46	10	44	sandy clay
	10-20	19	21	60	clay	48	8	44	sandy clay
	20-30	13	20	67	clay	34	12	54	clay
	30-40	10	20	70	clay	16	12	72	clay
	40-50	8	23	69	clay	2	30	68	clay
Hole 4	0-10	9	25	64	clay	9	31	60	clay
	10-20	12	20	68	clay	26	22	52	clay
	20-30	7	23	70	clay	0	40	60	clay
	30-40	20	30	50	clay	0	38	62	clay
	40-50	16	30	54	clay	0	40	60	clay
Hole 5	0-10	n.d.	n.d.	n.d.	n.d.	7	31	62	clay
	10-20	n.d.	n.d.	n.d.	n.d.	10	34	56	clay
	20-30	n.d.	n.d.	n.d.	n.d.	8	28	54	clay
	30-40	n.d.	n.d.	n.d.	n.d.	1	35	64	clay
	40-50	n.d.	n.d.	n.d.	n.d.	1	29	70	clay

(continued)

Appendix I (continued)

Location and Depth (cm)		SKUNK CREEK TRANSECT 12 % Sand	% Silt	% Clay	Soil Type	LITTLE BALSAM TRANSECT 5 % Sand	% Silt	% Clay	Soil Type
Hole 1	0-10	86	10	4	sand	10	46	44	silty clay
	10-20	88	7	5	sand	2	38	60	clay
	20-30	90	5	5	sand	2	32	66	clay
	30-40	85	7	8	sand	8	28	64	clay
	40-50	84	9	7	loamy sand	4	30	66	clay
	0-10	51	19	30	sandy clay loam	12	38	50	clay
	10-20	14	20	66	clay	12	38	50	clay
	20-30	10	16	74	clay	10	40	50	silty clay
	30-40	4	14	82	clay	8	38	54	clay
	40-50	4	10	86	clay	10	36	54	clay
	0-10	62	14	24	sandy clay loam	8	40	52	clay
	10-20	64	10	26	sandy clay loam	10	36	54	clay
	20-30	48	12	40	clay loam	10	36	54	clay
	30-40	8	19	73	clay	8	38	54	clay
	40-50	8	57	35	silty clay loam	8	36	56	clay
	0-10	59	12	29	sandy clay loam	8	34	58	clay
	10-20	34	18	48	clay	8	29	63	clay
	20-30	20	20	60	clay	8	27	65	clay
	30-40	4	22	74	clay	8	26	66	clay
	40-50	8	26	66	clay	7	26	67	clay
	0-10	34	28	38	clay loam	0	16	84	clay
	10-20	30	26	44	clay	0	14	86	clay
	20-30	28	26	46	clay	2	18	80	clay
	30-40	34	22	44	clay	0	12	88	clay
	40-50	32	22	46	clay	0	16	84	clay

(continued)

Appendix I (continued)

Location and Depth (cm)		LITTLE BALSAM TRANSECT 6 % Sand	% Silt	% Clay	Soil Type	LITTLE BALSAM TRANSECT 8 % Sand	% Silt	% Clay	Soil Type
Hole 1	0-10	30	26	44	clay	24	30	46	clay
	10-20	16	30	54	clay	16	28	56	clay
	20-30	10	26	64	clay	6	22	72	clay
	30-40	4	28	68	clay	0	16	84	clay
	40-50	4	28	68	clay	0	16	84	clay
Hole 2	0-10	28	25	47	clay				
	10-20	18	24	58	clay				
	20-30	12	26	62	clay				
	30-40	10	26	64	clay				
	40-50	8	24	68	clay				
Hole 3	0-10	24	22	54	clay				
	10-20	22	22	56	clay				
	20-30	14	16	70	clay				
	30-40	2	16	82	clay				
	40-50	2	18	80	clay				
Hole 4	0-10	26	26	48	clay				
	10-20	28	22	50	clay				
	20-30	34	18	48	clay				
	30-40	24	16	60	clay				
	40-50	18	16	66	clay				
Hole 5	0-10	26	29	45	clay				
	10-20	12	26	62	clay				
	20-30	10	22	68	clay				
	30-40	14	16	70	clay				
	40-50	24	18	58	clay				

(continued)

Appendix I (continued)

Location and Depth (cm)	LITTLE BALSAM TRANSECT 9 % Sand	% Silt	% Clay	Soil Type	LITTLE BALSAM TRANSECT 10 % Sand	% Silt	% Clay	Soil Type
Hole 1 0-10	80	16	4	loamy sand	74	12	14	sandy loam
10-20	84	12	4	loamy sand	84	6	10	loamy sand
20-30	90	4	6	sand	94	0	6	sand
30-40	84	10	6	loamy sand	80	6	14	sandy loam
40-50	76	14	10	sandy loam	90	2	8	sand
Hole 2 0-10	n.d.	n.d.	n.d.	n.d.	76	12	12	sandy loam
10-20	n.d.	n.d.	n.d.	n.d.	76	10	14	sandy loam
20-30	38	30	32	clay loam	80	6	14	sandy loam
30-40	20	34	46	clay	74	6	20	sandy loam
40-50	18	33	49	clay	78	8	14	sandy loam
0-10	24	30	46	clay	76	10	14	sandy loam
10-20	16	30	54	clay	78	8	14	sandy loam
20-30	16	30	54	clay	86	8	6	loamy sand
30-40	22	24	54	clay	88	2	10	loamy sand
40-50	22	24	54	clay	92	2	6	sand
Hole 4 0-10	52	26	22	sandy clay loam	80	10	10	sandy loam
10-20	48	22	30	sandy clay loam	82	6	12	sandy loam
20-30	48	20	32	sandy clay loam	84	6	10	loamy sand
30-40	46	24	30	clay loam	86	4	10	loamy sand
40-50	60	18	22	sandy clay loam	86	4	10	loamy sand
Hole 5 0-10	82	10	8	loamy sand	86	8	6	loamy sand
10-20	80	10	10	loamy sand	84	8	8	loamy sand
20-30	66	20	14	sandy loam	86	8	6	loamy sand
30-40	42	42	16	loam	86	8	6	loamy sand
40-50	25	35	40	clay loam	88	4	8	loamy sand

APPENDIX I

B. Organic carbon and pH measurements of soils from 5 depths at each location from Skunk Creek Transects 1, 6, 12 and Little Balsam Transects 5, 6, 7, 8, 10.

Location and Depth (cm)		SKUNK CREEK TRANSECT 1		SKUNK CREEK TRANSECT 6		SKUNK CREEK TRANSECT 12		LITTLE BALSAM TRANSECT 5	
		pH	% Org. C	pH	% Org. C	pH	% Org. C	pH	% Org. C
Hole 1	0-10	5.30	2.55	6.21	0.57	4.20	1.26	7.20	2.84
	10-20	5.20	1.17	6.30	0.09	3.94	0.18	7.20	1.01
	20-30	5.40	0.60	7.80	0.06	3.92	0.39	7.30	0.57
	30-40	6.90	0.36	6.82	0.05	4.07	0.39	7.10	0.46
	40-50	6.40	0.30	6.89	0.05	4.20	0.18	7.01	0.57
Hole 2	0-10	5.75	1.80	6.55	0.83	5.48	6.30	7.10	2.06
	10-20	6.00	0.84	6.71	0.44	6.42	1.11	6.90	0.93
	20-30	6.85	0.36	6.90	0.07	7.10	0.45	7.30	0.68
	30-40	7.50	0.24	7.35	0.05	7.50	0.27	7.29	0.74
	40-50	7.80	0.18	6.30	0.06	7.80	0.24	7.12	0.51
Hole 3	0-10	6.10	2.34	6.50	0.41	7.55	3.30	6.92	0.93
	10-20	6.30	1.23	6.41	0.10	6.90	0.91	7.59	0.68
	20-30	6.99	0.12	6.60	0.09	7.75	0.30	7.50	0.93
	30-40	7.30	0.12	7.31	0.07	7.39	0.20	7.55	0.52
	40-50	7.41	0.21	7.81	0.05	6.80	0.28	7.80	0.67
Hole 4	0-10	7.10	2.10	6.49	0.65	6.29	3.93	7.39	0.73
	10-20	7.30	0.65	6.60	0.26	6.65	1.20	7.20	0.85
	20-30	7.38	0.36	7.55	0.10	6.70	0.72	7.40	1.14
	30-40	7.54	0.12	7.00	0.07	7.30	0.24	7.25	0.69
	40-50	7.61	0.00	7.85	0.06	7.65	0.21	7.30	0.57
Hole 5	0-10	n.d.	n.d.	6.50	1.34	6.99	3.72	8.00	0.32
	10-20	n.d.	n.d.	6.89	0.57	7.25	1.38	7.85	0.40
	20-30	n.d.	n.d.	7.30	0.22	7.80	0.60	7.20	0.31
	30-40	n.d.	n.d.	7.61	0.13	7.90	0.42	7.30	0.15
	40-50	n.d.	n.d.	7.16	0.09	7.95	0.42	7.20	0.00

(continued)

Appendix I (continued)

Location and Depth (cm)		LITTLE BALSAM TRANSECT 6 pH	LITTLE BALSAM TRANSECT 6 % Org. C	LITTLE BALSAM TRANSECT 7 pH	LITTLE BALSAM TRANSECT 7 % Org. C	LITTLE BALSAM TRANSECT 8 pH	LITTLE BALSAM TRANSECT 8 % Org. C	LITTLE BALSAM TRANSECT 10 pH	LITTLE BALSAM TRANSECT 10 % Org. C
Hole 1	0-10	6.70	3.61	5.60	2.67	5.20	0.90	6.50	0.34
	10-20	6.20	1.81	6.05	1.32	5.10	0.36	6.25	0.37
	20-30	6.80	1.44	6.50	0.68	5.10	0.36	5.87	0.09
	30-40	6.90	0.41	6.83	0.48	5.20	0.42	6.48	0.05
	40-50	7.00	0.57	7.10	0.39	5.40	0.18	6.30	0.05
Hole 2	0-10	6.00	3.56	n.d.	n.d.	n.d.	n.d.	6.43	0.36
	10-20	7.20	1.65	n.d.	n.d.	n.d.	n.d.	6.19	0.14
	20-30	6.70	1.34	n.d.	n.d.	5.25	0.36	6.75	0.11
	30-40	6.70	0.62	n.d.	n.d.	6.60	0.38	6.13	0.11
	40-50	7.20	0.62	n.d.	n.d.	7.25	0.15	6.38	0.07
Hole 3	0-10	7.15	3.51	n.d.	n.d.	5.69	1.59	6.02	0.32
	10-20	7.12	1.75	n.d.	n.d.	6.05	0.60	6.70	0.05
	20-30	7.20	0.80	n.d.	n.d.	6.22	0.48	6.50	0.07
	30-40	7.35	0.46	n.d.	n.d.	6.51	0.36	6.41	0.03
	40-50	7.20	0.52	n.d.	n.d.	6.80	0.21	6.09	0.03
Hole 4	0-10	7.00	3.92	n.d.	n.d.	5.70	1.91	6.23	0.31
	10-20	7.15	2.12	n.d.	n.d.	5.55	0.67	6.20	0.11
	20-30	6.80	0.83	n.d.	n.d.	5.70	0.51	7.23	0.06
	30-40	6.74	0.52	n.d.	n.d.	5.65	0.33	6.55	0.03
	40-50	6.80	0.62	n.d.	n.d.	5.70	0.33	6.48	0.05
Hole 5	0-10	6.50	3.04	n.d.	n.d.	5.32	1.04	6.99	2.58
	10-20	6.80	1.70	n.d.	n.d.	5.40	0.48	7.22	1.14
	20-30	6.80	1.08	n.d.	n.d.	5.65	0.30	7.40	0.57
	30-40	7.35	0.52	n.d.	n.d.	6.00	0.30	7.30	0.36
	40-50	6.55	0.36	n.d.	n.d.	5.98	0.21	7.10	0.10

APPENDIX I

C. Exchangeable Mg, K and Ca (ppm) in soils of Skunk Creek Transect 6 and Little Balsam Transect 10.

		Skunk Creek Transect 6			Little Balsam Transect 10		
		Mg	K	Ca	Mg	K	Ca
Hole 1	0-10	208	15.0	97.5	19.5	6.6	145.0
	10-20	78	5.8	n.d.	3.2	2.0	38.8
	20-30	198	20.8	67.5	1.5	2.5	38.8
	30-40	212	23.3	>720	0.0	2.0	25.0
	40-50	190	n.d.	>750	0.0	3.4	25.0
Hole 2	0-10	126	13.3	97.5	10.0	6.2	105.0
	10-20	104	7.8	n.d.	7.0	4.2	67.5
	20-30	98	4.0	n.d.	5.5	1.0	67.5
	30-40	126	6.7	n.d.	3.2	1.0	52.5
	40-50	318	15.8	322.5	3.2	0.3	52.5
Hole 3	0-10	190	18.3	45.0	28.2	9.2	132.5
	10-20	176	13.3	n.d.	10.0	5.2	67.5
	20-30	218	17.5	67.5	9.0	3.8	67.5
	30-40	198	26.7	382.5	4.0	1.6	38.8
	40-50	168	29.2	>660	1.5	1.0	67.5
Hole 4	0-10	198	25.0	>660	19.5	9.6	157.5
	10-20	126	19.1	>623	10.0	1.6	80.0
	20-30	84	17.5	>458	7.0	1.6	67.5
	30-40	92	16.7	495	1.5	1.0	52.5
	40-50	84	20.8	510	0.0	0.8	38.8
Hole 5	0-10	318	28.3	>608	14.0	8.8	145.0
	10-20	218	21.7	397.5	7.0	0.2	80.0
	20-30	168	20.0	472.5	3.2	1.6	52.5
	30-40	212	18.3	547.5	5.5	0.0	67.5
	40-50	184	15.8	497.0	7.0	0.0	67.5

APPENDIX II

Summaries of root mass and length for each excavation site

BALSAM T-6, HOLE 1

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	2.3382	1.5318	1.4738	1.1821	1.1384	1.0544	********	********	********	********	********	********	2.5299
2	0.9038	0.5432	********	********	********	********	********	********	********	********	********	********	1.0609
3	0.0362	-0.1374	********	********	********	********	********	********	********	********	********	********	0.2590
4	-0.6128	-1.0603	********	********	********	********	********	********	********	********	********	********	-0.4803
5	********	********	********	********	********	********	********	********	********	********	********	********	********
TOTALS	2.3565	1.5836	1.4738	1.1821	1.1384	1.0544	********	********	********	********	********	********	2.5470

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ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	5.4414	4.0052	3.4443	2.7838	2.4237	2.1715	********	********	********	********	********	********	5.4627
2	4.0070	3.0165	********	********	********	********	********	********	********	********	********	********	4.0492
3	3.1393	2.3359	********	********	********	********	********	********	********	********	********	********	3.2027
4	2.4903	1.4130	********	********	********	********	********	********	********	********	********	********	2.5252
5	********	********	********	********	********	********	********	********	********	********	********	********	********
TOTALS	5.4596	4.0569	3.4443	2.7838	2.4237	2.1715	********	********	********	********	********	********	5.4819

BALSAM T-6, HOLE 2

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	2.5779	1.9613	1.8310	1.4018	1.0028	1.0268	0.9650	********	********	********	********	********	2.7728
2	1.5885	1.1085	0.7702	-0.3968	0.1708	0.2073	********	********	********	********	********	********	1.7852
3	-0.1360	-0.0982	-0.6344	-0.3187	********	-0.0357	********	********	********	********	********	********	0.4998
4	-0.3610	0.3682	********	********	********	********	********	********	********	********	********	********	0.4424
5	0.0031	********	********	********	********	********	********	********	********	********	********	********	0.0031
TOTALS	2.6225	2.0312	1.8685	1.4167	1.0625	1.1195	0.9650	********	********	********	********	********	2.8199

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	5.6811	4.4347	3.8014	3.0035	2.2882	2.1438	1.9239	********	********	********	********	********	5.7116
2	4.6917	3.5818	2.7407	1.2050	1.4561	1.3244	********	********	********	********	********	********	4.7292
3	2.9672	2.3751	1.3361	1.2831	********	1.0813	********	********	********	********	********	********	3.0853
4	2.7422	2.8415	********	********	********	********	********	********	********	********	********	********	3.0956
5	3.1062	********	********	********	********	********	********	********	********	********	********	********	3.1062
TOTALS	5.7257	4.5045	3.8390	3.0184	2.3478	2.2366	1.9239	********	********	********	********	********	5.7574

BALSAM T-6, HOLE 3

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	2.4662	1.4833	1.5173	1.4810	1.1763	0.9329	0.8313	********	********	********	********	********	2.6195
2	0.3266	0.4092	-0.1249	0.1652	********	********	********	********	********	********	********	********	0.8387
3	0.5481	0.1489	0.1598	0.0737	********	********	********	********	********	********	********	********	0.8791
4	0.1610	-0.0695	0.0261	-0.7211	********	********	********	********	********	********	********	********	0.5505
5	-0.2911	-0.5375	-0.1073	-0.0246	********	********	********	********	********	********	********	********	0.4026
TOTALS	2.4773	1.5507	1.5675	1.5321	1.1763	0.9329	0.8313	********	********	********	********	********	2.6404

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	5.5693	3.9566	3.4877	3.0828	2.4616	2.0500	1.8126	********	********	********	********	********	5.5852
2	3.4297	2.8826	1.8455	1.7670	********	********	********	********	********	********	********	********	3.5540
3	3.6513	2.6222	2.1303	1.6755	********	********	********	********	********	********	********	********	3.7059
4	3.2642	2.4038	1.9966	0.8807	********	********	********	********	********	********	********	********	3.3419
5	2.8121	1.9358	1.8631	1.5772	********	********	********	********	********	********	********	********	2.9272
TOTALS	5.5805	4.0241	3.5380	3.1339	2.4616	2.0500	1.8126	********	********	********	********	********	5.5982

BALSAM T-6, HOLE 4

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	2.6174	1.8070	1.4439	1.2435	1.0735	1.1082	1.2390	0.2281	********	********	********	********	2.7539
2	1.2474	0.5113	0.7026	0.2188	0.3049	0.4036	0.1489	********	********	********	********	********	1.5259
3	0.5410	0.4278	0.5631	0.1835	********	********	********	********	********	********	********	********	1.0544
4	0.6287	0.4261	0.5516	1.1128	********	********	********	********	********	********	********	********	1.3700
5	0.4754	0.2753	0.6836	0.4539	********	********	********	********	********	********	********	********	1.0983
TOTALS	2.6462	1.8727	1.6519	1.5623	1.1418	1.1864	1.2729	0.2281	********	********	********	********	2.8118

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	5.7206	4.2804	3.4144	2.8453	2.3589	2.2253	3.2349	1.5795	********	********	********	********	5.7404
2	4.3505	2.9846	2.6731	1.8205	1.5902	1.5206	0.6988	********	********	********	********	********	4.3801
3	3.6441	2.9011	2.5336	1.7853	********	********	********	********	********	********	********	********	3.7486
4	3.7319	2.8995	2.5220	2.7146	********	********	********	********	********	********	********	********	3.8474
5	3.5786	2.7486	2.6540	2.0557	********	********	********	********	********	********	********	********	3.6914
TOTALS	5.7493	4.3460	3.6224	3.1641	2.4271	2.3035	3.2362	1.5795	********	********	********	********	5.7720

BALSAM T-6, HOLE 5

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	2.5157	2.2021	1.9391	1.8226	1.5374	1.5457	1.5883	0.7818	********	********	********	********	2.8778
2	0.6859	0.2781	0.6016	0.0674	********	********	********	********	********	********	********	********	1.0759
3	0.3398	0.0785	0.5240	0.2971	-0.2620	0.1014	********	********	********	********	********	********	1.0218
4	-0.1354	-0.1811	0.3721	0.5343	-0.0405	********	********	********	********	********	********	********	0.9073
5	-0.1193	0.1368	0.4156	0.6256	-0.8180	********	********	********	********	********	********	********	0.9593
TOTALS													
	2.5268	2.2159	1.9965	1.8879	1.5572	1.5610	1.5883	0.7818	********	********	********	********	2.9000

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	5.6188	4.6755	3.9095	3.4244	2.8227	2.6628	2.2401	1.2550	********	********	********	********	5.6769
2	3.7891	2.7514	2.5720	1.6692	********	********	********	********	********	********	********	********	3.8535
3	3.4429	2.5518	2.4945	1.8988	1.0234	1.2185	********	********	********	********	********	********	3.5499
4	2.9678	2.2923	2.3426	2.1361	1.2449	********	********	********	********	********	********	********	3.1757
5	2.9838	2.6101	2.3860	2.2274	0.4673	********	********	********	********	********	********	********	3.2518
TOTALS													
	5.6300	4.6892	3.9670	3.4897	2.8425	2.6781	2.2401	1.2550	********	********	********	********	5.6894

BALSAM T-9, HOLE 1

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	2.2955	1.3832	1.5558	1.5769	1.3600	1.2979	1.4785	0.8719	********	********	********	2.4727	2.8277
2	1.7159	1.0499	1.2691	1.1860	1.1778	1.3507	1.3020	********	1.7649	********	********	********	2.3279
3	1.6300	1.2892	1.1866	0.8696	0.7068	0.4292	********	********	********	********	********	********	2.1638
4	1.5356	1.2141	1.0471	0.8909	0.7665	0.9050	1.3463	********	********	********	********	********	2.0239
5	1.3345	0.8892	1.1357	0.7541	0.8240	********	********	********	********	********	********	********	1.7431
TOTALS													
	2.5415	1.8973	1.9763	1.8689	1.7447	1.7242	1.9417	1.6581	1.7649	********	********	2.4727	3.0762

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	5.3986	3.8565	3.5263	3.1787	2.6453	2.4150	2.4664	1.2302	********	********	********	2.0167	5.4209
2	4.8191	3.5232	3.2395	2.7878	2.4631	2.4678	2.4909	********	1.7631	********	********	********	4.8607
3	4.7331	3.7625	3.1571	2.4714	1.9921	1.5463	********	********	********	********	********	********	4.7906
4	4.6388	3.6874	3.0175	2.4927	2.0519	2.0221	0.3010	********	********	********	********	********	4.6987
5	4.4376	3.3625	3.1061	2.3558	2.1093	********	********	********	********	********	********	********	4.4959
TOTALS													
	5.6447	4.3707	3.9468	3.4706	3.0300	2.8413	2.7813	1.2302	1.7631	********	********	2.0167	5.6804

BALSAM T-9, HOLE 2

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	1.7821	1.4550	1.6012	1.3991	1.4075	1.5433	1.7910	1.7314	********	********	********	********	2.5762
2	0.8383	1.2932	1.4047	1.2184	1.0157	1.0667	********	********	********	********	********	********	2.1720
3	0.7140	0.7001	1.0414	0.8100	1.1212	-0.6695	1.3644	0.5647	********	********	********	********	1.8317
4	0.8543	0.9399	0.8474	0.9003	0.9259	0.8498	********	********	********	********	********	********	1.8159
5	0.5274	0.6458	0.7463	0.5895	0.1089	0.1931	********	********	********	********	********	********	1.5450
TOTALS	1.9197	1.8214	1.9489	1.7773	1.7697	1.7438	2.1569	1.8820	********	********	********	********	2.8412

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	4.8852	3.9283	3.5716	3.0009	2.6929	2.6604	2.4679	2.1034	********	********	********	********	4.9607
2	3.9415	3.7665	3.3751	2.8202	2.3010	2.1838	********	********	********	********	********	********	4.2544
3	3.8172	3.1734	3.0118	2.4118	2.4066	0.4476	2.2064	0.9998	********	********	********	********	3.9898
4	3.9574	3.4132	2.8178	2.5021	2.2112	1.9668	********	********	********	********	********	********	4.1100
5	3.6305	3.1191	2.7167	2.1913	1.3942	1.3102	********	********	********	********	********	********	3.7998
TOTALS	5.0228	4.2947	3.9194	3.3791	3.0550	2.8609	2.6575	2.1363	********	********	********	********	5.1406

BALSAM T-9, HOLE 1

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	1.3972	1.3822	1.6685	1.5057	1.4080	1.4066	1.3125	1.6055	********	********	********	********	2.3794
2	1.0844	1.4629	1.5620	1.1910	1.1419	0.4623	1.4059	********	********	********	********	********	2.1315
3	1.1675	0.7695	1.0048	0.9829	1.0299	0.2727	1.6026	2.2495	2.2160	********	********	********	2.6384
4	0.1144	0.6505	1.0268	0.7226	0.6485	0.2922	0.9409	********	********	********	********	********	1.5660
5	0.0364	-0.3839	0.5187	0.5028	0.0282	0.4754	********	********	********	********	********	********	1.0805
TOTALS	1.7339	1.8055	2.0298	1.8171	1.7456	1.5468	1.9766	2.3383	2.2160	********	********	********	2.9337

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	4.5003	3.8555	3.6389	3.1074	2.6933	2.5237	2.1457	1.8059	********	********	********	********	4.6578
2	4.1875	3.9362	3.5324	2.7928	2.4272	1.5794	1.2550	********	********	********	********	********	4.4530
3	4.2706	3.2429	2.9753	2.5847	2.3152	1.3898	2.1519	2.3669	2.0331	********	********	********	4.3510
4	3.2176	3.1238	2.9972	2.3244	1.9339	1.4092	1.8192	********	********	********	********	********	3.6396
5	3.1395	2.0895	2.4891	2.1046	1.3135	1.5925	********	********	********	********	********	********	3.3003
TOTALS	4.8370	4.2788	4.0003	3.4188	3.0309	2.6639	2.5630	2.4723	2.0331	********	********	********	5.0112

BALSAM T-9, HOLE 4

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	1.9832	1.4665	1.6384	1.5096	1.4023	1.2685	1.6927	1.6337	0.8746	********	********	********	2.5375
2	1.3456	1.0837	1.3714	1.2416	1.0401	0.9506	1.8459	********	********	********	********	********	2.2181
3	1.0942	0.8443	1.1751	1.1895	0.8588	1.0873	0.8273	1.1651	0.8158	1.4508	********	********	2.0982
4	0.8936	0.6419	1.0443	0.7551	0.8174	0.5562	1.4307	1.2334	1.4599	1.6662	********	********	2.1996
5	0.5905	0.7172	1.0875	0.9099	0.7246	0.8439	1.6791	********	0.2924	0.7979	********	********	1.9900
TOTALS	2.1537	1.7632	2.0223	1.8979	1.7427	1.7014	2.3028	1.8736	1.6515	1.9078	********	********	2.9500

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	5.0863	3.9398	3.6089	3.1114	2.6876	2.3856	2.3706	1.9187	0.9541	********	********	********	5.1370
2	4.4487	3.5570	3.3419	2.8434	2.3255	2.0677	2.5033	********	********	********	********	********	4.5471
3	4.1973	3.3176	3.1456	2.7913	2.1441	2.2044	1.5795	1.5049	0.6988	1.3008	********	********	4.3062
4	3.9967	3.1152	3.0148	2.3568	2.1027	1.6733	2.3006	1.8448	1.5312	1.4311	********	********	4.1137
5	3.6937	3.1905	3.0579	2.5117	2.0100	1.9610	2.3780	********	0.4770	0.9029	********	********	3.9242
TOTALS	5.2569	4.2365	3.9927	3.4996	3.0281	2.8184	3.0127	2.2668	1.7073	1.7400	********	********	5.3303

BALSAM T-9, HOLE 5

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	1.9265	1.5177	1.5479	1.3493	1.2604	1.3315	1.8195	1.1594	1.1467	1.1709	********	********	2.5103
2	1.3228	1.1227	1.2293	0.9249	0.8191	1.1709	1.4203	1.3782	********	********	********	********	2.1181
3	1.3004	1.1178	1.2837	1.2784	0.9029	1.0822	1.2129	********	********	********	********	********	2.0321
4	1.1135	0.9001	0.7361	0.8744	0.6267	0.4862	0.7233	0.7353	********	********	********	********	1.7149
5	0.6535	0.6838	1.1070	0.8973	0.6248	0.5718	0.0730	1.8632	********	********	********	********	2.0496
TOTALS	2.1550	1.8578	1.9528	1.8137	1.6153	1.7415	2.0610	2.0671	1.1467	1.1709	********	********	2.8613

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	5.0297	3.9910	3.5183	2.9511	2.5457	2.4485	2.4277	1.2785	0.9998	0.6988	********	********	5.0863
2	4.4260	3.5960	3.1998	2.5267	2.1045	2.2880	2.4244	1.9634	********	********	********	********	4.5212
3	4.4036	3.5911	3.2541	2.8802	2.1882	2.1993	1.7850	********	********	********	********	********	4.5072
4	4.2167	3.3735	2.7065	2.4761	1.9121	1.6033	1.6625	0.9998	********	********	********	********	4.2970
5	3.7566	3.1571	3.0775	2.4991	1.9101	1.6889	1.3008	1.5560	********	********	********	********	3.9465
TOTALS	5.2582	4.3311	3.9232	3.4155	2.9007	2.8585	2.8197	2.1955	0.9998	0.6988	********	********	5.3343

BALSAM T-10, HOLE 1

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	1.2175	1.2536	1.2167	1.0061	0.5648	1.0660	1.0489	0.4268	********	********	********	********	1.9551
2	1.2344	1.2177	1.2423	0.8255	1.4390	1.3009	1.0988	********	********	********	********	********	2.0712
3	1.4963	1.1998	1.1172	0.8626	0.9233	0.7359	1.5986	********	********	********	********	********	2.0830
4	1.2392	1.3162	1.2882	0.7529	0.3085	-0.5883	1.2255	1.0246	********	1.8531	********	********	2.2150
5	0.9745	0.9796	0.5746	0.2924	-0.3487	0.8758	0.5107	0.8658	********	0.0941	********	********	1.6480
TOTALS													
	1.9626	1.9058	1.8463	1.5015	1.6233	1.6517	1.9215	1.3137	********	1.8606	********	********	2.7303

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	4.3206	3.7269	3.1871	2.6078	1.8501	2.1831	1.6432	0.6020	********	********	********	********	4.4543
2	4.3375	3.6910	3.2128	2.4273	2.7244	2.4179	1.9392	********	********	********	********	********	4.4689
3	4.5994	3.6732	3.0877	2.4644	2.2086	1.8530	2.2941	********	********	********	********	********	4.6666
4	4.3423	3.7895	3.2587	2.3547	1.5938	0.5288	1.8973	1.3008	********	1.5560	********	********	4.4824
5	4.0777	3.4529	2.5451	1.8942	0.9367	1.9929	1.3422	1.1759	********	0.0000	********	********	4.1866
TOTALS													
	5.0658	4.3792	3.8168	3.1033	2.9087	2.7687	2.6320	1.5908	********	1.5679	********	********	5.1761

BALSAM T-10, HOLE 2

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	1.3864	1.3857	1.4240	1.4108	1.3184	1.2362	1.7890	1.2699	0.8089	********	********	1.8479	2.4712
2	1.4712	1.5916	1.0623	0.6376	0.9737	0.2513	1.2892	********	********	********	********	********	2.0613
3	1.2877	1.2725	1.1697	1.0840	0.8533	1.2653	0.9935	********	********	********	********	********	2.0018
4	1.4191	0.9437	1.0194	0.6843	0.9937	0.4223	1.4594	********	********	********	********	********	1.9619
5	1.2342	1.1769	1.2947	0.3673	0.3738	1.2539	1.2477	********	1.8945	********	********	********	2.2320
TOTALS	2.0670	2.0248	1.9191	1.6936	1.6952	1.7634	2.1376	1.2699	1.9287	********	********	1.8479	2.8884

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ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	4.4896	3.8591	3.3944	3.0126	2.6038	2.3533	2.4853	1.6432	1.0412	********	********	1.5182	4.6296
2	4.5743	4.0649	3.0328	2.2393	2.2591	1.3684	2.0208	********	********	********	********	********	4.7049
3	4.3908	3.7459	3.1402	2.6857	2.1386	2.3823	1.7921	********	********	********	********	********	4.5114
4	4.5223	3.4170	2.9898	2.2861	2.2790	1.5394	2.0371	********	********	********	********	********	4.5728
5	4.3374	3.6503	3.2652	1.9691	1.6591	2.3710	2.0371	********	1.7778	********	********	********	4.4563
TOTALS	5.1702	4.4981	3.8896	3.2953	2.9806	2.8805	2.8390	1.6432	1.8509	********	********	1.5182	5.2827

BALSAM T-10, HOLE 3

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	1.6548	1.5758	1.4065	1.3525	1.3459	1.2553	0.6827	********	********	********	********	********	2.2449
2	1.3947	1.3125	1.0672	0.9848	0.6192	0.9913	1.0503	********	********	********	********	********	1.9630
3	1.3163	1.1961	1.1521	0.4750	0.6609	0.0496	1.1586	********	********	********	********	********	1.8674
4	0.7539	1.2650	0.9382	0.6169	0.2971	0.5249	0.8900	********	********	********	********	********	1.6987
5	0.7796	0.9322	0.9206	0.7108	0.5019	********	1.4654	********	********	********	********	********	1.7810
TOTALS													
	2.0102	2.0036	1.8347	1.6476	1.5572	1.5087	1.8286	********	********	********	********	********	2.6547

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	4.7580	4.0491	3.3769	2.9543	2.6313	2.3723	1.4469	********	********	********	********	********	4.8600
2	4.4979	3.7858	3.0376	2.5866	1.9045	2.1083	2.0167	********	********	********	********	********	4.5950
3	4.4194	3.6694	3.1226	2.0768	1.9463	1.1667	1.8570	********	********	********	********	********	4.5126
4	3.8571	3.7383	2.9086	2.2187	1.5824	1.6420	2.0930	********	********	********	********	********	4.1414
5	3.8828	3.4055	2.8910	2.3125	1.7873	********	2.1102	********	********	********	********	********	4.0550
TOTALS													
	5.1133	4.4769	3.8052	3.2494	2.8425	2.6258	2.6594	********	********	********	********	********	5.2292

BALSAM T-10, HOLE 4

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	2.1698	1.5708	1.6086	1.3272	1.0935	1.0468	1.4407	********	********	********	********	********	2.4741
2	1.6207	1.4643	1.3470	1.2901	1.1524	0.9264	1.4913	1.1784	********	********	********	********	2.2583
3	1.1808	1.1100	2.0031	2.0153	1.8256	1.1187	1.8644	********	********	********	********	********	2.5860
4	0.6578	0.6287	1.0069	-0.2276	0.3510	0.3598	1.0068	********	********	********	********	********	1.5344
5	0.8443	0.5693	0.3877	-0.2456	0.1959	-0.3080	********	********	********	********	********	********	1.1977
TOTALS	2.3350	1.9404	2.2458	2.1628	1.9883	1.5502	2.1519	1.1784	********	********	********	********	2.9612

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	5.2729	4.0441	3.5790	2.9289	2.3789	2.1638	1.9681	********	********	********	********	********	5.3089
2	4.7238	3.9377	3.3175	2.8919	2.4377	2.0435	2.1068	1.5182	********	********	********	********	4.8129
3	4.2840	3.5834	3.9736	3.6171	3.1109	2.2358	2.5033	********	********	********	********	********	4.5841
4	3.7610	3.1020	2.9773	1.3741	1.6363	1.4768	1.7479	********	********	********	********	********	3.9102
5	3.9474	3.0426	2.3582	1.3562	1.4812	0.8091	********	********	********	********	********	********	4.0107
TOTALS	5.4381	4.4137	4.2163	3.7645	3.2736	2.6672	2.7747	1.5182	********	********	********	********	5.5124

BALSAM T-10, HOLE 5

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	1.6931	1.6364	1.2007	1.3465	1.3521	1.4008	1.6519	1.4762	********	********	********	********	2.4032
2	1.4351	1.1145	1.4901	1.1072	1.4590	0.9246	1.5781	0.1920	********	********	********	********	2.2055
3	1.2681	1.0907	1.1561	1.2654	1.2450	1.3615	********	********	********	********	********	********	2.0177
4	0.9107	0.5947	0.7139	0.7896	1.1478	0.7870	********	********	********	********	********	********	1.6393
5	0.8794	0.8133	0.7618	0.7538	0.9208	0.5243	1.3898	********	********	********	********	********	1.7905
TOTALS	2.0445	1.8979	1.8576	1.8146	1.9601	1.8196	2.0303	1.4982	********	********	********	********	2.7944

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ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	4.7963	4.1097	3.1712	2.9483	2.6375	2.5179	2.3669	1.7631	********	********	********	********	4.8968
2	4.5382	3.5879	3.4605	2.7090	2.7444	2.0416	2.2918	0.4770	********	********	********	********	4.6300
3	4.3712	3.5640	3.1266	2.8672	2.5303	2.4786	********	********	********	********	********	********	4.4754
4	4.0139	3.0680	2.6844	2.3914	2.4332	1.9041	********	********	********	********	********	********	4.0995
5	3.9825	3.2866	2.7323	2.3555	2.2062	1.6414	2.2451	********	********	********	********	********	4.1033
TOTALS	5.1477	4.3712	3.8281	3.4163	3.2454	2.9367	2.7813	1.7850	********	********	********	********	5.2470

SKUNK T-6, HOLE 1

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	1.9656	1.6768	1.4861	1.3041	1.3972	1.4876	1.5260	1.5909	2.1281	0.4310	1.4101	********	2.6825
2	1.4709	1.2427	1.2927	1.1993	0.6120	0.8990	1.9132	********	1.5391	2.0007	********	********	2.4928
3	0.4022	1.3208	1.0165	0.8968	0.6741	0.6854	1.2869	********	********	********	********	********	1.8490
4	0.5347	0.8699	0.7939	0.7094	0.5152	0.5800	0.5489	********	********	********	********	********	1.5157
5	0.6574	0.4901	0.4147	0.3723	0.7051	0.4354	0.9003	********	********	********	********	********	1.4522
TOTALS	2.1220	1.9841	1.8416	1.7102	1.6244	1.6991	2.1651	1.5909	2.2276	2.0123	1.4101	********	2.9657

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	5.0688	4.1502	3.4565	2.9058	2.6826	2.6046	2.1610	1.8126	2.0208	0.3010	1.0790	********	5.1340
2	4.5740	3.7160	3.2632	2.8011	1.8974	2.0161	2.7011	********	1.6125	1.6718	********	********	4.6621
3	3.5053	3.7942	2.9870	2.4985	1.9594	1.8025	1.9953	********	********	********	********	********	4.0399
4	3.6378	3.3432	2.7643	2.3112	1.8006	1.6971	1.3615	********	********	********	********	********	3.8732
5	3.7605	2.9635	2.3852	1.9741	1.9905	1.5525	1.5679	********	********	********	********	********	3.8565
TOTALS	5.2251	4.4575	3.8120	3.3120	2.9097	2.8162	2.9063	1.8126	2.1640	1.6899	1.0790	********	5.3174

SKUNK T-6, HOLE 2

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	2.3455	2.1241	1.5053	1.4470	1.5265	1.6336	1.5959	0.2995	1.5518	1.6920	1.7837	0.6011	2.8338
2	1.4491	1.5162	1.5081	1.2858	1.4501	1.2640	1.5918	1.4272	1.3677	2.2534	********	********	2.6307
3	1.0686	1.3421	1.2709	0.9630	1.0329	1.0215	1.5498	0.0641	1.1974	********	********	********	2.1308
4	0.6490	0.9962	0.8379	0.5590	0.5106	0.0527	1.1402	********	********	********	********	********	1.6339
5	0.5577	1.0089	0.6099	0.7520	0.9292	0.2501	1.2267	1.1974	********	********	********	********	1.8222
TOTALS	2.4304	2.3180	1.9723	1.8178	1.9259	1.8738	2.1601	1.6594	1.8732	2.3587	1.7837	0.6011	3.1315

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	5.4486	4.5974	3.4758	3.0488	2.8118	2.7507	2.2037	0.3010	1.2550	1.5560	1.3008	1.5438	5.5133
2	4.5522	3.9895	3.4785	2.8875	2.7355	2.3811	2.1955	1.5438	1.3422	1.8322	********	********	4.7013
3	4.1717	3.8154	3.2413	2.5648	2.3182	2.1386	2.1000	0.6020	1.1459	********	********	********	4.3799
4	3.7522	3.4696	2.8083	2.1607	1.7959	1.1698	1.3008	********	********	********	********	********	3.9770
5	3.6609	3.4822	2.5804	2.3538	2.2146	1.3672	1.7990	1.4769	********	********	********	********	3.9294
TOTALS	5.5336	4.7913	3.9428	3.4196	3.2112	2.9909	2.7205	1.8509	1.7321	2.0167	1.3008	1.5438	5.6214

SKUNK T-6, HOLE 3

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	1.9263	1.8292	1.6733	1.3209	0.5635	0.9969	1.7023	1.1871	********	********	1.5107	********	2.5281
2	1.0878	1.4169	1.4716	0.9565	0.4444	0.9887	1.2766	1.5104	1.2407	********	0.7225	********	2.2134
3	0.2701	0.8342	0.9942	0.5280	0.4822	0.2792	0.7900	********	********	********	********	********	1.5188
4	0.5682	0.8599	1.0638	0.4570	0.3098	********	********	********	********	********	********	********	1.4381
5	0.2357	0.5635	0.6710	0.2535	-0.1687	********	********	********	********	********	********	********	1.0982
TOTALS	2.0166	2.0465	2.0123	1.5799	1.0861	1.3338	1.8777	1.6791	1.3647	********	1.5762	********	2.7587

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	5.0295	4.3025	3.6438	2.9227	1.8488	2.1139	2.4529	1.4311	********	********	1.1459	********	5.1233
2	4.1909	3.8902	3.4420	2.5583	1.7298	2.1057	1.5908	1.7400	1.4769	********	0.6020	********	4.4269
3	3.3732	3.3076	2.9646	2.1298	1.7675	1.3962	1.8126	********	********	********	********	********	3.7479
4	3.6713	3.3332	3.0342	2.0588	1.5951	********	********	********	********	********	********	********	3.9074
5	3.3389	3.0368	2.6414	1.8553	1.1166	********	********	********	********	********	********	********	3.5789
TOTALS	5.1198	4.5199	3.9827	3.1817	2.3715	2.4509	2.5884	1.9135	1.4769	********	1.2550	********	5.2480

SKUNK T-6, HOLE 4

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	1.9717	1.9255	1.5415	1.6329	1.2001	1.4267	1.2741	********	********	********	********	********	2.5010
2	1.4681	1.6222	1.4561	1.2950	1.1136	1.1593	1.4443	1.4701	1.7159	1.5572	********	********	2.4658
3	1.0256	1.3195	1.4561	1.1098	1.1459	1.0656	1.5752	1.3712	********	********	********	********	2.2031
4	0.8485	1.0264	0.9453	1.3317	0.6179	0.7630	1.0393	********	********	********	********	********	1.8378
5	0.7928	0.9796	0.8584	0.9615	0.4610	0.5167	0.0195	-0.3808	********	********	********	********	1.5993
TOTALS													
	2.1671	2.2230	2.0333	2.0258	1.6978	1.7913	1.9831	1.7278	1.7159	1.5572	********	********	2.9431

450

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	5.0748	4.3988	3.5120	3.2346	2.4854	2.5438	1.8918	********	********	********	********	********	5.1748
2	4.5713	4.0955	3.4265	2.8967	2.3989	2.2764	2.1426	1.8192	1.5312	1.3800	********	********	4.7314
3	4.1287	3.7929	3.4265	2.7115	2.4313	2.1827	2.1786	1.7631	********	********	********	********	4.3705
4	3.9517	3.4997	2.9157	2.9334	1.9033	1.8801	1.6809	********	********	********	********	********	4.1458
5	3.8959	3.4529	2.8289	2.5633	1.7463	1.6338	2.0488	1.3008	********	********	********	********	4.0783
TOTALS													
	5.2702	4.6964	4.0037	3.6276	2.9831	2.9083	2.7221	2.1580	1.5312	1.3800	********	********	5.4028

SKUNK T-6, HOLE 5

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	2.1563	1.8641	1.7395	1.3908	1.4261	0.9447	1.6532	1.6385	1.7315	2.0821	2.4544	2.7726	3.1677
2	1.6784	1.6779	1.1370	1.0941	1.1295	0.9203	1.8389	1.8634	1.3862	1.7461	1.6918	2.3070	2.7903
3	1.0115	1.0209	1.2034	1.0234	1.2015	0.3358	1.6861	1.5243	1.5529	********	2.2005	********	2.5335
4	0.8131	0.6799	0.9756	1.2788	0.7935	0.8266	1.6440	1.7698	********	********	********	********	2.1918
5	0.5755	0.6202	0.8915	0.9876	1.0876	1.1145	1.4704	********	********	0.3299	1.8511	********	2.1855
TOTALS	2.3253	2.1467	2.0077	1.8823	1.8721	1.5912	2.3731	2.3197	2.0566	2.2520	2.7508	2.9004	3.4374

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	5.2595	4.3375	3.7100	2.9925	2.7114	2.0617	2.1786	1.8385	1.7400	1.6987	1.9539	2.1899	5.3238
2	4.7815	4.1513	3.1074	2.6959	2.4148	2.0373	2.3071	2.3923	1.3008	1.5679	1.2785	1.6718	4.8884
3	4.1147	3.4942	3.1739	2.6252	2.4868	1.4529	2.2691	1.8862	1.5049	********	1.7240	********	4.2727
4	3.9162	3.1532	2.9460	2.8806	2.0788	1.9437	2.2524	1.9819	********	********	********	********	4.0716
5	3.6786	3.0935	2.8620	2.5894	2.3729	2.2316	2.2249	********	********	0.3010	1.4911	********	3.8884
TOTALS	5.4285	4.6201	3.9782	3.4841	3.1574	2.7082	2.9474	2.6888	2.0290	1.9490	2.2851	2.3049	5.5137

SKUNK T-12, HOLE 1

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	2.2458	1.7884	1.9667	1.7022	1.5394	1.3956	2.0766	2.0569	1.0425	1.7652	2.1933	2.5089	3.0867
2	1.7543	1.0698	1.3378	1.3068	1.1713	1.0033	1.3729	1.6423	********	********	********	********	2.3073
3	1.3065	1.1156	1.1341	1.0519	0.9647	0.8939	1.5864	0.7175	1.4062	2.1974	********	********	2.4800
4	1.3702	0.8417	1.1639	1.1016	0.9387	0.8612	1.5729	1.4233	2.1974	********	********	********	2.4697
5	1.5943	0.9456	1.4538	1.4896	1.2066	1.3204	1.8740	1.5946	0.9115	********	********	********	2.4259
TOTALS	2.4995	2.0085	2.2329	2.0983	1.9213	1.8509	2.4678	2.3596	2.3058	2.3340	2.1933	2.5089	3.3592

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	5.3489	4.2617	3.9372	3.3040	2.8247	2.5127	2.4937	2.3498	1.3977	1.7705	1.9187	1.7778	5.4048
2	4.8575	3.5431	3.3083	2.9086	2.4566	2.1204	2.0371	1.9341	********	********	********	********	4.8974
3	4.4097	3.5890	3.1046	2.6537	2.2500	2.0109	2.1983	1.0790	1.5049	1.2302	********	********	4.5022
4	4.4733	3.3150	3.1343	2.7033	2.2240	1.9783	2.1363	1.7240	1.7321	********	********	********	4.5337
5	4.6975	3.4189	3.4243	3.0914	2.4920	2.4375	2.5246	1.8805	1.1759	********	********	********	4.7590
TOTALS	5.6026	4.4818	4.2034	3.7000	3.2067	2.9679	3.0211	2.6537	2.1000	1.8805	1.9187	2.0965	5.6592

SKUNK T-12, HOLE 2

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	2.3852	1.5606	1.7014	1.3209	0.6804	0.6596	1.9239	1.9653	2.0275	1.6509	********	********	2.8370
2	1.0738	1.1271	1.4124	1.3537	1.1873	1.0663	1.7113	2.0265	1.1679	********	********	********	2.4363
3	0.6463	0.6765	0.8911	0.6337	0.4854	0.3096	1.7285	********	********	********	********	********	1.9023
4	0.3759	0.6451	0.8702	0.5429	0.9443	********	-0.2790	********	********	********	********	********	1.4316
5	-0.0699	0.1014	0.7768	0.1908	********	0.4538	0.9161	********	********	********	********	********	1.3166
TOTALS	2.4187	1.7794	1.9881	1.7230	1.5056	1.3242	2.2958	2.2980	2.0836	1.6509	********	********	3.0364

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	5.4883	4.0340	3.6719	2.9226	1.9657	1.7767	2.6508	2.1235	1.9135	1.1459	********	********	5.5119
2	4.1769	3.6004	3.3828	2.9555	2.4726	2.1834	2.5510	2.3218	0.9998	********	********	********	4.3683
3	3.7494	3.1499	2.8616	2.2354	1.7707	1.4266	2.4261	********	********	********	********	********	3.9179
4	3.4791	3.1184	2.8406	2.1446	2.2297	********	0.4770	********	********	********	********	********	3.7268
5	3.0333	2.5748	2.7473	1.7926	********	1.5709	1.5438	********	********	********	********	********	3.3320
TOTALS	5.5219	4.2528	3.9585	3.3248	2.7909	2.4413	3.0444	2.5348	1.9634	1.1459	********	********	5.5612

SKUNK T-12, HOLE 3

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	2.4783	1.6345	1.8951	1.5199	1.1891	1.0083	1.9348	1.5544	1.8521	1.8315	********	********	2.8703
2	1.7646	1.1339	1.2499	0.9847	0.4087	0.7576	1.5205	********	********	********	********	********	2.3043
3	1.1150	0.9308	1.0789	0.7844	0.2534	0.6001	1.4230	********	********	********	********	********	1.8566
4	0.5918	0.6543	0.7576	-0.0324	********	********	0.8108	********	********	********	********	********	1.3331
5	0.3864	0.0918	-0.1848	********	********	********	********	********	********	********	********	********	0.6358
TOTALS	2.5779	1.8511	2.0594	1.6969	1.2968	1.2987	2.1822	1.9858	1.8521	1.8315	********	********	3.0174

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	5.5815	4.1079	3.8656	3.1217	2.4744	2.1254	2.7311	1.8570	1.9081	1.5795	********	********	5.6065
2	4.8677	3.6073	3.2204	2.5865	1.6940	1.8747	2.4767	********	********	********	********	********	4.9045
3	4.2182	3.4041	3.0493	2.3862	1.5387	1.7172	2.0290	********	********	********	********	********	4.3142
4	3.6949	3.1276	2.7281	1.5693	********	********	1.7705	********	********	********	********	********	3.8404
5	3.4896	2.5652	1.7857	********	********	********	********	********	********	********	********	********	3.5460
TOTALS	5.6810	4.3244	4.0299	3.2987	2.5821	2.4158	3.0016	1.8570	1.9081	1.5795	********	********	5.7121

SKUNK T-12, HOLE 4

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	2.1039	1.7273	0.9746	1.5385	1.4948	1.3932	1.8788	1.7793	0.9334	********	********	********	2.6280
2	1.8535	1.4013	1.4768	1.1154	0.9371	1.2370	1.5546	********	********	********	********	********	2.3038
3	1.1827	0.9796	1.2171	0.9324	1.0605	1.1045	1.4455	0.9375	********	********	********	********	2.0435
4	0.8668	0.5835	1.3666	0.3791	0.8285	0.6642	1.3063	0.6527	********	********	********	********	1.8628
5	0.2920	0.4465	0.5744	0.4624	1.1371	0.0374	-0.1349	1.3602	********	********	********	********	1.6977
TOTALS													
	2.3481	1.9764	1.9185	1.7884	1.8563	1.7810	2.2050	1.9832	0.9334	********	********	********	2.9340

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	5.2070	4.2007	2.9450	3.1402	2.7801	2.5103	2.6420	1.8973	0.6988	********	********	********	5.2568
2	4.9566	3.8746	3.4473	2.7172	2.2224	2.3540	2.4145	********	********	********	********	********	5.0084
3	4.2859	3.4530	3.1875	2.5342	2.3459	2.2215	2.2829	1.2550	********	********	********	********	4.3914
4	3.9699	3.0568	3.3370	1.9808	2.1138	1.7813	2.1757	1.4621	********	********	********	********	4.1175
5	3.3951	2.9198	2.5449	2.0642	2.4224	1.1545	0.4770	1.7556	********	********	********	********	3.6149
TOTALS													
	5.4512	4.4498	3.8889	3.3902	3.1416	2.8981	3.0182	2.2620	0.6988	********	********	********	5.5111

SKUNK T-12, HOLE 5

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	1.5135	1.6522	1.6704	1.5651	1.3981	1.4113	2.2577	1.7923	********	********	********	1.9038	2.7282
2	1.6169	1.2069	1.3377	1.4497	0.8069	0.3318	1.6509	1.1593	0.6368	1.9417	********	********	2.4262
3	1.4983	0.9211	1.0925	1.2412	0.7822	0.3044	1.2597	1.6987	********	********	********	********	2.1638
4	1.1728	0.7193	1.0862	1.0127	0.7092	0.1778	0.8466	********	********	********	********	********	1.7501
5	0.6426	0.0996	0.9070	0.9112	1.1523	-0.0773	0.8855	0.9736	1.7090	********	********	********	2.0217
TOTALS	2.0961	1.8798	2.0052	2.0032	1.7542	1.5090	2.4127	2.1328	1.7442	1.9417	********	1.9038	3.0448

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	4.6166	4.1256	3.6409	3.1669	2.6834	2.5284	2.5361	2.1815	********	********	********	1.5312	4.7917
2	4.7200	3.6802	3.3081	3.0515	2.0922	1.4488	2.5473	1.5679	0.8449	1.6529	********	********	4.7855
3	4.6014	3.3945	3.0630	2.8429	2.0675	1.4215	2.0371	2.0290	********	********	********	********	4.6496
4	4.2759	3.1927	3.0567	2.6145	1.9946	1.2949	1.6432	********	********	********	********	********	4.3453
5	3.7458	2.5730	2.8775	2.5130	2.4376	1.0398	1.7321	1.3800	1.9996	********	********	********	3.8742
TOTALS	5.1992	4.3531	3.9756	3.6050	3.0395	2.6260	2.9556	2.5047	2.0290	1.6529	********	1.5312	5.2948

BALSAM T-5, HOLE 1

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	1.5497	1.3696	1.3924	1.3710	1.0057	0.9955	1.0536	********	********	********	********	********	2.1410
2	1.2823	0.9663	1.4922	1.6437	1.2512	0.7516	1.6916	0.8465	********	********	********	********	2.2627
3	0.7566	0.9971	1.3948	1.6399	0.6737	-0.3429	1.2288	0.9472	********	********	********	********	2.0608
4	0.6532	0.3564	0.7664	1.2629	0.5620	********	********	********	********	********	********	********	1.5387
5	0.4030	0.4715	1.4163	1.2241	1.0315	-0.7470	********	********	********	********	********	********	1.7726
TOTALS													
	1.8283	1.6797	2.0510	2.1649	1.6727	1.2087	1.8887	1.2007	********	********	********	********	2.7244

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	4.6528	3.8429	3.3628	2.9728	2.2911	2.1125	1.5182	********	********	********	********	********	4.7445
2	4.3854	3.4396	3.4627	3.2455	2.5365	1.8687	1.6987	1.3008	********	********	********	********	4.5077
3	3.8598	3.4705	3.3652	3.2417	1.9591	0.7742	1.8862	1.3220	********	********	********	********	4.1599
4	3.7563	2.8297	2.7368	2.8646	1.8473	********	********	********	********	********	********	********	3.8881
5	3.5061	2.9448	3.3867	2.8259	2.3169	0.3701	********	********	********	********	********	********	3.8693
TOTALS													
	4.9314	4.1530	4.0214	3.7667	2.9581	2.3258	2.2037	1.6125	********	********	********	********	5.0692

BALSAM T-5, HOLE 2

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	1.8662	1.2288	1.8752	2.0600	1.8993	1.8844	1.1431	********	********	********	********	********	2.6532
2	0.7600	0.5775	0.5914	1.3255	0.5936	0.5947	0.1402	********	********	********	********	********	1.6417
3	0.8401	0.5157	0.8858	1.3386	0.4686	********	********	********	********	********	********	********	1.6296
4	0.8873	0.2640	1.1300	1.4193	0.4500	-0.3372	********	********	********	********	********	********	1.7207
5	0.3359	0.5654	0.7257	1.6419	0.3151	0.8498	********	********	********	********	********	********	1.8071
TOTALS	1.9823	1.4698	2.0228	2.3576	1.9592	1.9450	1.1842	********	********	********	********	********	2.8149

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	4.9693	3.7021	3.8456	3.6618	3.1846	3.0015	2.2037	********	********	********	********	********	5.0511
2	3.8631	3.0508	2.5619	2.9273	1.8789	1.7118	1.2039	********	********	********	********	********	3.9900
3	3.9432	2.9890	2.8562	2.9403	1.7539	********	********	********	********	********	********	********	4.0567
4	3.9904	2.7373	3.1004	3.0211	1.7353	0.7799	********	********	********	********	********	********	4.1037
5	3.4390	3.0388	2.6961	3.2437	1.6004	1.9668	********	********	********	********	********	********	3.7939
TOTALS	5.0855	3.9432	3.9933	3.9594	3.2445	3.0620	2.2451	********	********	********	********	********	5.1834

BALSAM T-5, HOLE 3

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	1.5858	1.3768	1.3862	1.4620	0.2725	********	********	********	********	********	********	********	2.0700
2	0.6234	-0.2830	1.2464	1.7907	0.8039	0.1708	********	********	********	********	********	********	1.9636
3	-0.0975	0.5777	0.5843	1.8317	1.0204	0.1989	********	********	********	********	********	********	1.9462
4	-0.0175	0.0888	0.8555	1.6993	1.0324	********	********	********	********	********	********	********	1.8461
5	0.0552	-0.3798	0.8979	1.4688	1.1784	-0.0250	********	********	********	********	********	********	1.7396
TOTALS	1.6592	1.4735	1.7844	2.3766	1.6490	0.6027	********	********	********	********	********	********	2.6261

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ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	4.6890	3.8501	3.3566	3.0638	1.5578	********	********	********	********	********	********	********	4.7738
2	3.7266	2.1904	3.2169	3.3925	2.0893	1.2879	********	********	********	********	********	********	3.9886
3	3.0057	3.0511	2.5548	3.4335	2.3058	1.3160	********	********	********	********	********	********	3.7349
4	3.0857	2.5621	2.8259	3.3011	2.3178	********	********	********	********	********	********	********	3.6493
5	3.1583	2.0935	2.8683	3.0706	2.4637	1.0920	********	********	********	********	********	********	3.5776
TOTALS	4.7623	3.9469	3.7548	3.9784	2.9343	1.7198	********	********	********	********	********	********	4.9180

BALSAM T-5, HOLE 4

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	1.8614	1.4032	1.8813	2.0083	0.7409	0.1610	********	********	********	********	********	********	2.4516
2	0.9619	0.1587	0.9180	1.5912	0.3638	********	********	********	********	********	********	********	1.7796
3	0.7605	-0.3471	0.8468	1.6737	1.1157	-0.1233	********	********	********	********	********	********	1.8778
4	0.2183	-0.1655	0.8959	1.6627	1.2530	0.1275	0.5552	********	********	********	********	********	1.8977
5	0.1938	-0.1656	0.9598	1.7207	1.2171	0.8248	********	********	********	********	********	********	1.9399
TOTALS	1.9581	1.4557	2.0349	2.4573	1.7423	1.0095	0.6862	********	********	********	********	********	2.7668

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	4.9646	3.8765	3.8518	3.6101	2.0262	1.2781	********	********	********	********	********	********	5.0453
2	4.0651	2.6320	2.8884	3.1930	1.6491	********	********	********	********	********	********	********	4.1590
3	3.8637	2.1262	2.8173	3.2755	2.4010	0.9938	********	********	********	********	********	********	4.0104
4	3.3214	2.3078	2.8663	3.2645	2.5383	1.2445	0.3010	********	********	********	********	********	3.7191
5	3.2969	2.3077	2.9303	3.3224	2.5025	1.9419	********	********	********	********	********	********	3.7436
TOTALS	5.0613	3.9291	4.0053	4.0590	3.0276	2.1266	0.3010	********	********	********	********	********	5.1656

BALSAM T-5, HOLE 5

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	0.0648	-0.3673	0.7161	0.3554	0.0370	********	********	********	********	********	********	********	1.0062
2	-0.5936	-0.1875	0.3624	0.5475	0.6771	********	********	********	********	********	********	********	1.0602
3	0.0589	-0.2778	0.4440	0.5457	-0.1135	********	********	********	********	********	********	********	0.9412
4	-1.4087	0.0752	0.1889	0.7693	********	********	********	********	********	********	********	********	0.9370
5	-2.1545	-1.4434	-0.1426	-0.3356	********	********	********	********	********	********	********	********	0.0880
TOTALS													
	0.4161	0.4519	1.0985	1.1943	0.8204	********	********	********	********	********	********	********	1.6045

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	3.1680	2.1061	2.6866	1.9572	1.3223	********	********	********	********	********	********	********	3.3418
2	2.5095	2.2858	2.3328	2.1492	1.9624	********	********	********	********	********	********	********	2.9841
3	3.1620	2.1956	2.4144	2.1475	1.1718	********	********	********	********	********	********	********	3.3061
4	1.6945	2.5486	2.1593	2.3710	********	********	********	********	********	********	********	********	2.8933
5	0.9486	1.0299	1.8278	1.2661	********	********	********	********	********	********	********	********	2.0224
TOTALS													
	3.5192	2.9252	3.0690	2.7961	2.1057	********	********	********	********	********	********	********	3.7832

SKUNK T-1, HOLE1

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM, (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	2.0978	1.2806	1.4133	1.1898	1.3889	1.2156	1.5387	1.4398	********	********	********	********	2.4604
2	1.1734	1.0788	1.3810	1.1765	0.6700	0.7758	1.4700	********	********	********	********	********	2.0256
3	0.9765	1.2037	1.1264	1.0662	0.6492	0.5680	0.4468	********	********	********	********	********	1.7883
4	0.7062	1.0657	0.9247	1.1270	0.2695	********	0.7565	1.0432	********	********	********	********	1.7568
5	0.5338	0.7600	0.8463	0.2839	0.5072	0.6845	1.1603	********	********	********	********	********	1.6087
TOTALS	2.1990	1.8090	1.8961	1.7593	1.5876	1.4903	1.9397	1.5863	********	********	********	********	2.7433

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM, (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	5.2010	3.7539	3.3838	2.7916	2.6742	2.3326	2.2171	1.6432	********	********	********	********	5.2265
2	4.2766	3.5521	3.3515	2.7783	1.9554	1.8928	2.1332	********	********	********	********	********	4.4085
3	4.0796	3.6770	3.0969	2.6680	1.9345	1.6851	1.4469	********	********	********	********	********	4.2705
4	3.8093	3.5390	2.8952	2.7288	1.5548	********	0.7780	0.9998	********	********	********	********	4.0522
5	3.6370	3.2333	2.8168	1.8857	1.7926	1.8016	1.8509	********	********	********	********	********	3.8435
TOTALS	5.3021	4.2824	3.8666	3.3611	2.8729	2.6073	2.6081	1.7321	********	********	********	********	5.3635

SKUNK T-1, HOLE2

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	1.8564	1.5180	1.7530	1.7536	1.3374	1.3419	1.4664	1.9288	1.4714	********	********	********	2.6079
2	1.1059	1.0449	1.3317	1.3558	0.9426	1.2292	1.2195	1.5148	1.0765	********	********	********	2.1900
3	1.2671	0.8903	1.3083	1.2482	0.6958	0.9719	1.5722	0.9752	********	********	********	********	2.0983
4	0.9776	0.8148	1.1165	1.0871	0.7088	1.0034	0.2588	********	********	********	********	********	1.7658
5	0.9761	0.9118	0.8720	0.0926	0.2518	0.8083	1.4728	********	********	********	********	********	1.8076
TOTALS													
	2.0865	1.8228	2.0753	2.0435	1.6270	1.8115	2.0595	2.1039	1.6183	********	********	********	2.9074

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	4.9595	3.9913	3.7235	3.3553	2.6227	2.4589	2.1457	1.6125	1.2550	********	********	********	5.0388
2	4.2090	3.5183	3.3021	2.9576	2.2280	2.3462	1.9864	1.7400	1.1137	********	********	********	4.3607
3	4.3703	3.3636	3.2788	2.8499	1.9811	2.0890	2.4179	1.1459	********	********	********	********	4.4604
4	4.0808	3.2881	3.0870	2.6888	1.9941	2.1205	0.9541	********	********	********	********	********	4.2023
5	4.0792	3.3851	2.8425	1.6943	1.5371	1.9253	1.9135	********	********	********	********	********	4.1867
TOTALS													
	5.1896	4.2961	4.0457	3.6452	2.9123	2.9286	2.7704	2.0410	1.4911	********	********	********	5.2843

SKUNK T-1, HOLE3

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	1.9698	1.4368	1.6941	1.5030	1.4389	1.5233	1.7641	1.5617	1.4264	********	********	********	2.5841
2	1.1687	1.1103	1.3731	1.6607	1.3540	1.1710	1.7670	1.5679	********	********	********	********	2.3614
3	1.4040	1.1412	1.4027	1.4755	0.9991	2.0141	1.5963	********	********	********	********	********	2.3928
4	0.8415	0.8032	1.0616	0.8772	0.8428	0.5893	1.4835	1.1917	********	********	********	********	1.9502
5	-0.0841	0.4377	0.8222	0.8083	********	0.3077	1.5080	********	********	********	********	********	1.7064
TOTALS													
	2.1496	1.8004	2.0662	2.0844	1.8260	2.1970	2.3397	1.9492	1.4264	********	********	********	3.0002

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	5.0730	3.9102	3.6645	3.1048	2.7242	2.6404	2.2941	1.6018	1.2550	********	********	********	5.1256
2	4.2719	3.5836	3.3436	3.2625	2.6393	2.2881	2.4145	1.7631	********	********	********	********	4.4395
3	4.5071	3.6145	3.3732	3.0773	2.2844	3.1312	1.4769	********	********	********	********	********	4.6168
4	3.9447	3.2765	3.0321	2.4790	2.1282	1.7064	2.3320	1.4911	********	********	********	********	4.0969
5	3.0191	2.9110	2.7926	2.4101	********	1.4247	2.2426	********	********	********	********	********	3.4680
TOTALS													
	5.2527	4.2737	4.0366	3.6862	3.1114	3.3140	2.9425	2.1102	1.2550	********	********	********	5.3381

SKUNK T-1, HOLE4

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	1.7678	1.4938	1.7145	1.6290	1.6365	1.0104	1.3008	0.6722	2.0611	********	********	********	2.5799
2	1.1294	0.9490	0.9400	1.3072	1.1873	0.9904	1.1039	********	********	********	********	********	1.9504
3	0.7954	0.8973	1.1426	0.9871	1.0394	0.6735	1.3980	1.5094	********	********	********	********	2.0441
4	0.7220	0.9743	1.0085	1.0477	0.9685	0.8900	1.4380	0.6443	2.2086	********	********	********	2.3919
5	0.6163	0.8531	1.1053	0.7551	0.2360	********	1.2337	1.6101	1.1210	********	********	********	2.0106
TOTALS													
	1.9564	1.8096	1.9883	1.9513	1.9066	1.5118	2.0095	1.9146	2.4623	********	********	********	2.9679

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	4.8910	3.9671	3.6850	3.2308	2.9219	2.1274	2.3006	0.9998	1.9953	********	********	********	4.9773
2	4.2326	3.4223	2.9105	2.9090	2.4726	2.1075	1.9819	********	********	********	********	********	4.3399
3	3.8986	3.3707	3.1130	2.5889	2.3247	1.7906	2.1580	1.8805	********	********	********	********	4.0948
4	3.8251	3.4476	2.9790	2.6495	2.2538	2.0071	2.0290	1.0790	1.6809	********	********	********	4.0543
5	3.7195	3.3264	3.0757	2.3569	1.5213	********	1.8257	1.8322	1.2302	********	********	********	3.9525
TOTALS													
	5.0596	4.2829	3.9587	3.5530	3.1919	2.6289	2.7877	2.2197	2.2144	********	********	********	5.1746

BALSAM T-8, HOLE1

DATA IN LOG BASE 10, ********= NO ROOTS

ROOT BIOMASS -- GRAM O.D.W.

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	2.1016	1.3744	1.8072	1.8020	1.3192	1.3962	1.8424	1.4057	********	********	********	********	2.6214
2	1.1459	1.0468	1.4387	1.3969	0.9761	1.0088	1.5010	********	********	********	********	********	2.1101
3	1.0691	0.8209	1.2662	1.1988	0.7906	0.8923	1.4218	********	********	********	********	********	1.9683
4	0.8138	0.7024	0.7501	0.9128	0.7233	0.0035	1.3649	0.8847	********	********	********	********	1.7957
5	0.5199	0.2811	0.4622	0.3686	0.2631	********	0.6836	********	********	********	********	********	1.2332
TOTALS	2.2092	1.6847	2.0740	2.0593	1.6395	1.6426	2.1921	1.5200	********	********	********	********	2.8570

ROOT LENGTH (CM)

DEPTH (CM X 10**-1) / ROOT DIAM. (MM)

	-0.5	0.5-1	1-2	2-3	3-4	4-5	5-10	10-15	15-20	20-25	25-30	30+	TOTAL
1	5.2048	3.8478	3.7777	3.4037	2.6045	2.5133	2.3400	1.6125	********	********	********	********	5.2474
2	4.2491	3.5201	3.4091	2.9987	2.2615	2.1259	2.1300	********	********	********	********	********	4.3991
3	4.1722	3.2942	3.2367	2.8006	2.0759	2.0094	1.8747	********	********	********	********	********	4.2897
4	3.9170	3.1757	2.7205	2.5146	2.0087	1.1205	1.9135	1.2785	********	********	********	********	4.0344
5	3.6230	2.7544	2.4327	1.9704	1.5484	********	1.2302	********	********	********	********	********	3.7145
TOTALS	5.3123	4.1560	4.0444	3.6611	2.9248	2.7596	2.7221	1.7778	********	********	********	********	5.3753

RED CLAY PROJECT QUARTERLY REPORT
EVALUATION OF RCIC WORKS PROJECT
April 1, 1977

by
Garit Tenpas
William Briggs

Introduction

The Red Clay Interagency Committee which has been conducting erosion control and sediment reduction projects in Wisconsin since 1955 was invited by the Red Clay Project (Soil and Water Conservation District sponsors of Ashland, Douglas, Bayfield and Iron Counties) in a letter of April 16, 1976 from Stephen Andrews, Project Director, to George Wright to undertake some follow-up studies on its past activities in the Lake Superior basin. Specifically the nature of the study would be to evaluate the effects of erosion control measures introduced there after several years.

At its meeting on May 3, 1976, the RCIC members agreed to consider drafting a proposal contingent on a tour of the sites on June 3-4, 1976. The tour was conducted by the RCIC members with some of the staff of the Red Clay Project, one of the members of the Red Clay Project Executive Committee (Ila Bromberg) and for one of the sites, a local landowner, R. Galligan, a former member of the State Soil and Water Conservation District Committee also participated. At the end of the tour, it was agreed that the RCIC would make the proposal and invite Mr. William Briggs, a former member of the RCIC, employee of the Soil Conservation Service at Madison and now retired and Mr. Garit Tenpas, former director of the Wisconsin Experimental Station at Ashland, now located at Marshfield, to conduct the field studies.

A proposal was drafted by Messrs. W. Briggs, G. Tenpas, L. Massie, C. Laughter, and C. Kabat for the RCIC.

The proposal was accepted and Messrs W. Briggs and G. Tenpas completed their observations and field evaluation studies on July 20-21, 1976.

Procedures

Messrs. W. Briggs and G. Tenpas examined all of the sites on July 21-22, 1976 at which the RCIC conducted studies in the past. The selected sites were studied and current conditions recorded.

Following the field work, W. Briggs and G. Tenpas prepared their observations in a list under a format similar to that used to describe sites contained in past reports, particularly the "Second Progress Report by the Red Clay Interagency Committee, July 1964" (see Appendix II Worksites, Objectives, Results and Recommendations). Messrs. Briggs, Tenpas and Peterson prepared the rough drafts of the report. RCIC members reviewed the rough drafts, and recommended changes. The procedures for drafting the project proposal, reviewing and developing the report are contained in Appendix III, Minutes of the RCIC meetings.

Results and Recommendations

The results of the 1976 field work together with county maps showing locations of study sites are presented in Appendix II, Worksites, Objectives, Results, and Redommendations as an addition to prior information. This format achieves continuity of prior publications by the RCIC. Study sites on the maps are identified by numbers corresponding to those used in the narrative section.

Appendix II also includes some interim observations between 1963 and 1976 that had not been covered in previous publications. Two sites, Trask Creek and Airport Road, contained in previous reports, are dropped from the appendix because it was concluded by the RCIC that they were not substantive enough to warrant further documentation. Other than these two sites, the information on all other sites listed in Appendix II are contained in prior RCIC publications.

Appendix II contains detailed information on site characteristics, results of treatments and recommendations.

SPECIFIC RECOMMENDATIONS ON CRITICAL SITES ON THE RED CLAY SOILS OF NORTHERN WISCONSIN -- BASED ON STUDIES CONDUCTED BY THE RED CLAY INTERAGENCY COMMITTEE

Methods to control erosion by the establishment and maintenance of suitable vegetation have been tried and tested over a 10 to 15 year period. The recommendations discussed in this report are based on an evaluation of the trials conducted by the Red Clay Interagency Committee.

General Recommendations

A permanent desirable vegetation is established by selecting a suitable seeding mixture, inoculating all legumes, using adequate amounts of plant food and doing a good job of mulching the area. Prescription seeding for the particular site should be followed. A mixture of grasses and legumes are the most desirable, but grass may be used alone.

1. Banks - Cuts, Fills and Gullies

Due to moisture collecting in the soil from seepage frequent sloughing and slippage occurs on red clay cut and fill slopes.

a. Highway location and design.

It is recommended that where possible the alignment of the roadway be adjusted so as to reduce or eliminate side hill cut and fill sections by crossing the natural contours at right angles.

b. Sloping and seed bed preparation.

Shape the back slopes of cut sections to a 4:1 or flatter slope and fill sections to a 3:1 slope. A satisfactory seed bed should be prepared.

c. Fertilizer application.

Apply 500# of 20-10-10 (nitrogen-phosphate-potash) or its equivalent per acre. No lime is generally needed since the red clay road banks are usually calcareous.

d. Seeding mixture

Mixtures of grasses and legumes have generally provided a better ground cover than grasses alone. Long lived legumes such as Empire Birdsfoot Trefoil and Emerald Crown-vetch should be a part of mixtures where legumes are desired. Alfalfa and red alsike and white clovers usually have disappeared in a few years. Birdsfoot trefoil establishes quickly and has proven to be very persistent except in shady areas. Crownvetch is very persistent but it is slow to establish a thick stand and is not adapted to poorly-drained areas. Because birdsfoot trefoil is adapted over a wide range of conditions, and establishes easier than crownvetch it would be the legume of choice in most sites.

Northern brome grass and tall fescue have proven to be the most persistent and have the best ground cover of all the grass species tested. Avoid excessive amounts of competitive species, such as annual, domestic or perennial ryegrass often used to obtain a quick cover. Seeding without a nurse crop is the most desirable method when the seeding is mulched. When it is not possible to use a mulch then the addition of one bushel of small grain per acre to the mixture will help to establish a quick ground cover and aid in soil stabilization.

The basic seeding mixture should consist of the following:

6 to 8 pounds Empire Birdsfoot Trefoil

10 to 15 pounds Smooth Brome grass (Canadian or Sac)

5 pounds Tall Fescue (Alta or Ky 31)

5 pounds Emerald Crownvetch

On well-drained sites Northern Brome grass is well adapted and so Tall Fescue can be left out of the mixture. On poorly-drained sites Tall Fescue should replace the Northern Brome grass and crownvetch should be left out.

The highlights of the field studies are as follows: Generally the worksites observed are stabilized. Some changes in conditions since prior observations include a deterioration of the baskets containing rocks (Gabions) at the Brule River which have broken open, possibly caused by ice damage. Some of the rocks are slipping out. As expected, stands of birdsfoot trefoil and crownvetch either continue to predominate at the sites or have increased. There is some evidence that vegetation on some of the plots could be strengthened by adding fertilizer. Reed canary grass has taken over the vegetation in the Raspotnik Waterway, but was seeded by the landowner. Previously this was in brome grass and legumes. Other sites generally remain stabilized including the high bank (Galligan Farm) on the Whittlesey Creek, White River, Town of Eileen and the channel at the mouth of the Whittlesey Creek.

The one site that has changed the most since the late 1960's is the Hunt Waterway. This site which was formerly stabilized, has now been encroached on with cultivation extending into the waterway. This encroachment is a result of a tennant-farmer disregarding practical land use management.

Worksites, Objectives, Results and Recommendations

The locations and results of the field observations are contained in Appendix II which in addition to county maps keyed to each location, includes sites and characteristics, objectives, pretreatment and results of treatments from the date corrective erosion control action was taken through the summer of 1976.

Generally the bank and waterway stabilization practices were highly successful, except in the case of the Hunt Waterway where encroachment by cultivation occurred. The importance of stabilizing the toes of steep banks is exemplified at the Catlin Road Site (No. 3), the Galligan Brothers' farm on the Whittlesey Stream (No. 12), and the Brule River stream bank (No. 10). The importance of properly sloping the banks before applying vegetation establishment practices is exemplified on several sites, particularly Town of Eileen (No. 4) and White River (No. 6).

Specific Recommendations on Critical Sites

The results of the erosion control practices were utilized to update the specific recommendations for critical site erosion control. These are presented in the remainder of this section. Details of erosion control practices, their relationship to land use management, photographs of sites and equipment, and related information are contained in the following reports authored by the Red Clay Interagency Committee: 1957. Whittlesey Watershed; 1960. Whittlesey Watershed; a program report of the Red Clay Interagency Committee, 1964. Second progress report by the Red Clay Interagency Committee and 1967. Erosion and sedimentation control on the red clay soil of northwestern Wisconsin, Soil Conservation Board, Madison, Wisconsin.

e. Time of seeding.

To obtain the best legume-grass stands the seeding should be made as early in the year as practical but not later than July 15. Legume seedings made later may survive under very favorable circumstances but the chances of success are poor. Grasses can normally be seeded until September 1.

When seedings must be made late in the season, it may be desirable to seed only the grasses and seed the legumes the following spring. Successful seedings have often been made by broadcasting the legume seed on the surface of the ground after the snow has melted but while the ground is freezing at night and thawing during the day. This freezing and thawing action allows the dense legume seed to work its way into the soil.

f. Mulching.

Mulching is an essential step for all successful seedings. Straw mulch (1 1/2 tons per acre) with slow-setting asphalt emulsion (150 gallons per acre) has consistently proven to be the most practical and effective mulch tried to date. Grass hay and asphalt emulsion would rate below straw but both have been superior to wood products such as Turf-fiber.

g. Maintenance.

After the desired legumes and grasses have become established mowing is not considered necessary except for control of weeds. Subsequent fertilizer treatments have not proven necessary especially where a high percentage of legumes in the mixture provides the nitrogen needed for good grass growth. Do not spray legumes with herbicides. Remove undesirable woody species (trees and shrubs) from sensitive slopes.

2. Grassed Waterways

a. Seed bed preparation.

The waterway must be properly designed and shaped.

b. Lime and fertilizer application.

Get a soil test and apply lime and fertilizer accordingly. If available, spread approximately 15 tons of barnyard manure per acre. Work the fertilizer and manure into the top 3 to 4 inches of soil. Seed and mulch immediately.

c. Seed mixtures.

In seeding mixtures using several species, the vegetation on critical area seedings can be expected to vary considerably from year-to-year until one or two species predominates or becomes the climax species on that site.

Well-drained waterways: In well-drained waterways Empire Birdsfoot Trefoil and Creeping Red Fescue have proven to be excellent climax species and can withstand high velocity flow. Brome and tall fescue are included for quick cover. The grass waterway seeding mixture should consist of the following mixture per acre:

6 to 8 pounds Empire Birdsfoot Trefoil
10 pounds Northern Brome grass
10 pounds Tall Fescue
3 pounds Creeping Red Fescue

Poorly-drained waterways: In poorly-drained waterways that are too wet to support birdsfoot trefoil and Creeping Red Fescue, it has been determined that Reeds Canary Grass thrives and becomes the climax species. The following seeding mixture is recommended per acre:

10 to 15 pounds Reeds Canary Grass

Some have been successful with an alternative method of disking Reeds Canary Grass sprigs into the ditch bottom.

d. Time of seeding.

See recommendations for Banks - Cuts, Fills and Gullies.

e. Mulching.

See recommendations for Banks - Cuts, Fills and Gullies.

Good protection is provided by a heavy jute mesh ("Soil Saver" -- a Ludlow product). It comes in 4'x225' rolls. No special equipment is necessary but its use is largely dependent upon availability of hand labor.

3. Stream Banks

a. Sloping and seed bed preparation.

High velocity drainages should be diverted before runoff reaches the face of the slope. Tops of slopes should be rounded to remove overhangs. Rills and gullies should be filled where possible.

b. Toe stabilization.

Wherever bank erosion is occurring or is potential, toe stabilization is necessary to prevent stream deterioration and at times complete destruction through sedimentation. Several techniques were tested.

Gabions: The installation of Gabions at the toe of the bank is one of the best practices. These consist of wire baskets filled with rocks. The Gabions are commercially constructed of #9 or heavier wire and should be a corrosion resisting metal. While installation is relatively simple, assistance should be solicited from the Department of Natural Resources and Soil Conservation Service personnel.

Some failures on these Gabions has been noted after 12 years due to poor quality wires.

Rock Rip-Rap: The use of rock rip-rap backed by a suitable bed of filter material is also an alternative proven means of toe stabilization.

Sheathing and Deflectors: Installation of sheathing and deflectors and stream diversion are other important methods of toe stabilization and protection. Measures to stabilize the toe of slopes must extend vertically to the high water elevation.

c. Seeding and mulching.

After achieving adequate toe stabilization, Reeds Canary Grass at 10 to 15 pounds per acre or spriggings (sod pieces) with one foot spacing should be used from the waterline to the high watermark. For critical areas above the high waterline use the seeding and mulching recommendation for Banks.

WORK SITES - METHODS AND OBSERVATIONS

Sites and Characteristics	Objectives and Experimental Work Performed and Date	Results and Recommendations
Agriculture - waterways		
(1) Hunt Waterway (1958) Constructed waterway on CR land. Cut into red clay subsoil. The seeded area was flooded by a hard runoff resulting from culvert area field drainage. The waterway and field were seeded under CR in spring 1958 in separate operations.	Hand seed and fertilize 20 plots with mixtures of grass & legumes and 400 #/acre of 10-10-10 in the waterway. Mulch with Fin equipment. The mulch was not tied or disked into soil. Reseed and mulch site in 1959.	In 1958 mulch floated and washed away in heavy July rainfall - severe cutting occurred in waterway on lower 2/3 of its length. August 28, 1958, legumes showed up well where soil was not washed away. Alsike was poor, alfalfa, trefoil and red clover were good. Grasses were weak with perennial ryegrass being best. On May 1959, alfalfa, trefoil and red clover dominated their plots. Alsike poor, grass growth was weak; but the best stands were made by ryegrass, orchard and southern brome. The 1959 reseeding was successful. Some washing occurred 2nd year. As of 1963, BF-trefoil has sealed the old scars and stabilized these spots. 7-21-76 Adjoining field has been worked up and seeded to oats (meadow). Waterway from the road culvert to about plot 10 has been completely reworked. (This is to the area where the waterway turns north.) Some remnants of species can be found in worked up areas. Some digging occurred on rest of planting. Cover is excellent of any species still remaining. On wet areas reed canarygrass looks excellent but needs some maintenance. The combination of BF-trefoil and red fescue looks very good and is considered the best plot today. Orchardgrass, ryegrass, alfalfa, red clover and several other species except for occasional remnants disappeared from the waterway several years ago.

Sites and Characteristics	Objectives and Experimental Work Performed and Date	Results and Recommendations
(2) Raspotnik Waterway (6-27-61) Off Highway 63. About 600 feet long. Shaped, graded, mulched and seeded by Red Clay Committee. Very vulnerable to erosion without a formed waterway and stabilization treatments.	Stabilize waterway. Seed and mulch with three treatments. Upper-Turfiber; middle-hay disked into soil with Turfiber on top; lower-hay disked into soil topped with asphalt-hay mulch. Seed mixture per acre S. brome. 40 #; seaside bent 4 #; timothy 4 #; BF-trefoil 4 #.	1961 seeding successful. All mulch treatments effective. 1962 sod weakened by grazing but still effective. 1963, the waterway is stabilized, especially if grazing is prevented. 1963. Overall the waterway rates very good. Predominantly brome grass today. Very few breaks. The waterway is considered stabilized. 7-20-76 Excellent waterway. No gullying found. Reed canarygrass is the predominant species. It was seeded by the farmer without any ground preparation using a cyclone seeder probably in 1962. Few remnants of brome and BF-trefoil can still be observed. Center of waterway needs mowing. This was recommended to the farmer.
Road Banks		
(3) Experimental Plot(1958) Catlin Road (Whittlesey Watershed). Raw bank, south slope 1:3 slope. Soil very wet. Prepared seed bed in some plots with Klodbuster. Klodbuster did not clog with wet clay, where used. The other sites even though they were badly rilled were not dragged before seeding.	Develop methods of establishing bank cover and determine results of seeding three replicate plots of bluegrass, red fescue, red top, d. ryegrass, wh. dutch clover. All plots were hand seeded, fertilizer followed by mulching.	By 1959 the legumes were taking over, mostly sw. clover and alfalfa; grasses were poor. Ground cover good first year - holding second year. Presoaking of seed showed no advantage. Some volunteer sweet clover and spots of mulch remained. 1959-62: Bank erosion continued in the badly rilled sites. As of 1963: Generally the bank is stabilized (BF-trefoil dominant, volunteer?). It was observed that the north road ditch needed a drop structure of some sort. 6-15-65 Estimated content of vegetation is: Kentucky bluegrass ...... 30-40% Quackgrass .... 20-30% Red Fescue .... 20-30% Alfalfa 10-20%

Sites and Characteristics	Objectives and Experimental Work Performed and Date	Results and Recommendations
		7-20-76 Road has been widened probably in 1975. North bank appears completely reshaped and re-seeded. Today this bank consists of a fair stand of young crownvetch. Washing in the ditch bottom on the north side (west end) remains a problem since no drop structure has been added. Willows along the south side of the road have helped stabilize the toe of the down slope. Mixed vegetation is excellent.
(4) Town of Eileen (1959) Relocation of the north-south road and construction of a new bridge left raw red clay slopes approximately 300 feet long on the southern approadh to the new bridge. The slope of the bank coming down the road toward the bridge varied from 0 to 40 feet. To reduce costs the slopes were graded with a 1-1/2 to 1 side slope when wet. As a result the soil was so hard and compacted that numerous passes with the Klodbuster barely scratched the surface.	1959: Establish vegetative cover rapidly to prevent excessive erosion and bank slippage. The latter objective is difficult but it was felt a good cover would help. The entire area was seeded with a standard mixture of 30# per acre of Kentucky bluegrass 40%; red fescue 30%; red top 15%; domestic ryegrass 10%; white clover 5%. After seeding the area was thoroughly mulched with straw and the asphalt was applied heavier than normal.	1959: Ten days after seeding - despite frequent heavy rains, the mulch held well. W. wheat and barley were beginning to sprout. Three weeks after seeding the W. wheat and barley were growing rapidly and thickly; the entire area was green. Under the mulch a lot of grass and legume seeds were sprouting. By October 31, the barley and W. wheat were 8-12 inches high. The small grass and legume plants were very prolific though in number quite small. In two places the steep banks showed some slippage. Where the mulch cover was adequate and uniform the growth was good, but where it was thin or missed, the growth was very poor or absent. 1960-62: Despite good sod cover the steeply graded banks collapsed.

Sites and Characteristics	Objectives and Experimental Work Performed and Date	Results and Recommendations
1963 (June 12). After the bank collapsed, the sites were regraded (slopes 3-4' to 1'), reseeded and mulched.	1963: Stabilize bank with Turfiber, straw-asphalt and Glassroot mulch treatments. Glassroot (a discontinued product of Pittsburgh Plate Glass Co. fiber glass product) was applied in the waterway as well as one plot on the slope. Seeding mix: 10# Empire BF-trefoil; 10# Emerald crownvetch; 10# Creeping red fescue.	1963: Because of extreme droughty conditions all vegetative growth was retarded. Under Turfiber growth was negligible and best under the straw-asphalt mulch. Glassroot completely prevented erosion in both sites. 1964 - Seedings rate fair. 6-14-1965 Birdsfoot trefoil is good. Emerald crownvetch where established is good. Grass is short of nitrogen. Fall, 1965 Birdsfoot trefoil rates excellent. Some poplars invading on north end and should be removed. 7-20-1976 Birdsfoot trefoil and crownvetch doing an excellent job of stabilization. This is an outstanding example of what can and should be done. It appears that part of the area needs fertility. Crownvetch on north end excellent. Birdsfoot trefoil rates excellent. Reed canarygrass in wet areas is excellent. No washing in ditches. Poplars still present. All grasses and legumes used here have a place in roadside stabilization.
(5) Sand River (Highway 13)(1959) A new highway development. The seeding was near the bridge construction. This area has been seeded unsuccessfully the previous year. No soil preparation was possible because of wet ground and inaccessibility to site with equipment.	6/3-5 1958 Determine if mulching and fertilizing with the mulcher and hydroseeder will produce a better growth of bank vegetation than the conventional methods used to establish cover. Control areas received only the conventional treatment of sloping, grading and seeding standard roadside mixture of	1959-60: Doubled mulched plots showed improved growth. Upper and drier portions of the slope had the poorest seeding. Double fertilization showed improved growth. Road bank well established but ditch bottom showed considerable washing. Unmulched area on top of slope would rate 9 on stand on scale of 1-10 with 10 representing a complete failure. Mulched areas would rate 5-6 on stand. Much variation between species performance. In general legumes, alfalfa, red clover, BF-trefoil and white clover looked the best.

Sites and Characteristics	Objectives and Experimental Work Performed and Date	Results and Recommendations
	30# per acre of Kentucky bluegrass 40%; red fescue 30%; red top 15%; domestic ryegrass 10%; white clover 5%. Test various seeding mixtures and rates put on in 10x60 foot plots. Both grasses and legumes were used.	Alsike clover and the vetches gave very poor stands. Of the grasses timothy and ryegrass and red top looked promising. Reed canary, bluegrass, brome and the fescues were generally quite poor. 1961-63: Crownvetch growth spectacular; some plots now solid with crownvetch. BF-trefoil very strong in all plots; grasses almost gone. Slippage continues at "soil-breaks." Under good sod between "soil-breaks" there is no bank slippage. 7-20-1976 The county has removed material that has moved down into the road ditch and today only a few skips remain. The cover is 95% or more and the whole area is fairly well stabilized. BF-trefoil is the predominant species on both sides of the road. Remnants from most of the original grasses used can be found. This includes brome, reed canarygrass, red fescue and tall fescue. The grass plots are a light green color and the need for additional nitrogen fertilization is clearly indicated. A small amount of woody invasion is occurring and this should be eliminated.
(6) White River(1960) The State Highway Commission rebuilt this road with well-shaped and graded banks. Study plots on banks and ditches were left for the committee. The remainder of the banks and waterways were hydroseeded (standard highway mix) and mulched by a contractor.	Compare seeding mixtures and fertilizer treatments, install and observe Ludlow "soil-saver" in a road ditch for erosion control value. The seed mixtures, plot locations and results are given in the Appendix of the 2nd Progress Report of the RCIC, 1964. Seeded June 29, 1960.	1960-63: All seeding mixtures showed excellent growth the first year with tall fescue being most outstanding among both grasses and legumes. Alfalfa topped the legumes in 1960. As of 1963, BF-trefoil dominates all vegetation with crownvetch also showing spectacular growth in some places now holding over 50% of a plot. Reed canarygrass is strong among grasses with tall fescue and smooth brome following. (See Trials on the White River Site in the Appendix).

Sites and Characteristics	Objectives and Experimental Work Performed and Date	Results and Recommendations
		Nitrogen topdressing has shown striking results in improving sod stands. Potash and phosphate showed only a small response. In road ditch, "soil saver" controlled erosion but vegetative growth slow and poor. 6-14-1965 BF-trefoil shows up very strong. Most perennial grasses provided very satisfactory cover. Birdsfoot trefoil and crownvetch rate best of legumes by far. 7-21-1976 BF-trefoil and Emerald crownvetch have persisted and out-performed alfalfa, red clover and Alsike clover. Of the grasses that were seeded, one still finds amounts of tall fescue, creeping red fescue and northern brome gras. Their persistence is in the same order as given. Their stand is from fair to good. Tall fescue should be recommended for sandy sites. Reed canarygrass has persisted very well and shows excellent growth. However, it is tall and should be recommended for the wet site only. The road ditch today is 50% Birdsfoot trefoil; 45% Reed canarygrass; and 5% Garrison creeping foxtail.
(7) Douglas County(1962) A south shore park area, newly graded with graduated slope to Lake Superior on red clay soils. Douglas County requested assistance in stabilizing this bank.	Rapidly stabilize this area using Finn hydroseeder and Turfiber. The International Paper Company to supply all equipment and operators. Employ standard seed mixtures and Turfiber rates.	Although moisture conditions were excellent, all sod species grew slowly, in fact, the only growth during the summer of 1962 was in the "rills." By 1963 sod cover developed satisfactorily with BF-trefoil predominating. In 1975, a great deal of BF-trefoil present. There is still an unstable bank above the lake. This simply verifies the need for toe stabilization of lake shore eorsion.

Sites and Characteristics	Objectives and Experimental Work Performed and Date	Results and Recommendations
(8) Miscellaneous Road Banks Near Ashland(1962) Several small sites were involved for Turfiber supplemental work.	To get supplemental information on Turfiber. Apply seed mixtures and Turfiber with the hydroseeder (4#'s BF-trefoil; 4#'s tall fescue; and 1# perennial ryegrass; 10-10-10 fertilizer and 1-1/2 bales of Turfiber per acre.	1962: The only growth was in the rills with tall fescue predominating. BF-trefoil though included in the seeding, was almost absent. 1963: Though the overall seeding failed the erosion control result was successful. The rills are stabilized with the grass growth filling in between the rills.
(9) Wanabo Road(1964) Two miles west of Washburn. Bare, south exposed red clay banks.	Using Turfiber as mulch with and without oats. Seedbed worked up lightly by hand prior to seeding. Accidently in one hydroseeder load 2400 #/acre 10-10-10 was used. Seeded 6-9-1964.	Very heavy rain on night of seeding 6-9-1964 nearly completely washed off Turfiber, and probably most of plant food. 9-12-1964 No growth of any vegetation except sparce growth of crownvetch. 7-20-1976 Emerald crownvetch has gradually taken over. Some BF-trefoil is still left. Today the area treated has 95% cover and the adjacent check area is about 45% covered. One conclusion of this trial is that Turfiber and similar cellulose mulches will not provide adequate mulch for uniform moisture condition during the germination of the seedling. In similar areas where straw mulch was used, complete cover and stabilization took place within a couple of years.

Sites and Characteristics	Objectives and Experimental Work Performed and Date	Results and Recommendations
(10) Brule River Mulching and Seeding On Department of Natural Resources land north of Highway 13 near the Brule. Roadside site treated was a road ditch bank and the ditch itself. Location along a town road. Drainage is both ways. There has been extremely heavy deer traffic.	Using seed mixture best adapted to site but using various mulching methods. This included glassroot and straw mulch. Seed mixture 50% Canadian brome; 25% tall fescue; and 25% BF-trefoil. The trefoil was not inoculated. 400 # 10-10-10 seeded by hand July 16, 1964.	9-23-1964 Total vegetation is best on straw mulch plots. Fair to good stand of brome and tall fescue. BF-trefoil could be found, but all plants were small and spindly (presumably lack of inoculation). In areas of heavy deer traffic, the glassroot had mostly disappeared. It was carried off when tangled in deer hoofs. Ribbon grass has made good growth and rows are easily seen from the road. 7-20-1976 Deer still keep parts of stand trampled. Grass cover pretty well has stabilized the bank. BF-trefoil still a small portion of the stand.
In area west of mulched area by small stream, some ribbon grass was transplanted.	To observe ribbon grass.	Some ribbon grass shows up well in large clumps. Ribbon grass is very attractive, but reed canarygrass, would have likely done much better.
(11) University of Wisconsin Experiment Station Road Ditch and Shoulder (1967) Newly graded red clay roadsides.	To put into practice best recommendation to date. To try glassroot in road ditch. Try some pre-soaked seed. Seeded 6-13-1967. Brome grass 10# P/A Tall fescue 5# BF-trefoil 5# Crownvetch 5# on some areas	1967 - No special benefits from the pre-soaked seeds. Glassroot in the ditch bottoms washed out by heavy rains the day after seeding (on 6-14-1967). It piled up by road culvert. Undoubtedly much seed from road ditch also washed away. 7-21-1976 Stand basically is excellent and predominantly BF-trefoil. Crownvetch and brome grass are also good. Perennial sweetpea persists to this date at most plot divisions. There is some invasion of weeds on both sides of the road; however, the ditches are now stabilized.

Sites and Characteristics	Objectives and Experimental Work Performed and Date	Results and Recommendations
	Fertilized 266 #/A with 16-8-8. All mulched with straw mulch 1-1/2 T/A with 150 gallons asphalt emulsion P/A. Seeded both sides of road.	
(12) Madigan Road(1967) Red clay soils located on the road to the Odana Campsite and Picnic Area. Natural vegetation has covered a portion of the area and other sites which had not yet revegetated were used for this study.	Putting into practice the best findings to date. Use of glassroot on steep road ditch. 400# 16-10-10; 10# BF-trefoil; 7# tall fescue; 1# Kentucky bluegrass; and 1# creeping red fescue. Areas were seeded and fertilized in one operation with a hydroseeder. Stage mulch was applied by hand by an Indian work crew about a day later. Seeded 6-13-1967.	Seeding came good and establishment was rapid. Birdsfoot trefoil consistently rated excellent. The steepest valley with the glassroot continued to erode. 7-19-1976 Roadside well stabilized by BF-trefoil. Excellent stand. On steep area where glassroot was used, erosion has been curtailed, but some cutting still occurring. Woody vegetation--mostly willows and poplars--invading rather badly.
(13) Birch Hill - Lower Falls Road Near Iron County line. Some rather sandy sites, but some of the lower Falls road is clayey (1967)	Application of findings to date. 250# 16-10-10; 3# BF-trefoil; 3# Emerald crownvetch; 3# tall fescue; and 1# creeping red fescue. Seeded 6-13-1967. Seeded with hydroseeder and straw mulch was spread with an Indian highway crew a day later. Hand planting of perennial sweetpea on bank beyond reach of hydroseeder.	Birdsfoot trefoil came good where seeded. On the upper part of the big bank, some perennial sweetpea is growing. 7-19-1976 Excellent stand of BF-trefoil on roadside, on fills, and on steep banks where seeded. Perennial sweetpea has persisted for nine years and looks good. Willow, birch and quacking aspen invading hillside, especially on upper part. On the sandy portion of the fill, spotted knapweed, undesirable for stabilization, is spreading rapidly.

Sites and Characteristics	Objectives and Experimental Work Performed and Date	Results and Recommendations
(14) Long Road, Marengo(1968) East and west one-mile long road -- cuts and fills on both sides. Mixed soil conditions.	To try on a full sized scale the best of red clay findings to date. This was approximately 7 acres in size. Hydroseeder and mulcher used. 350# 10-10-10 fertilizer used per acre. Seeding mixture per acre: BF-trefoil 10# Timothy 3# Oats 15# Last load had 1# Kentucky bluegrass that went on about 2 acres in the mixture. Used straw, some excelsior and some chopped hay.	8-28-1968 Good seeding except on southern exposed slopes. Excelsior was used as a mulch but it failed since it did not adhere to the soil and the wind blew it off the slope in 1968. 1975 Basically the seeding has accomplished its purpose. 7-21-1976 Ditches and banks are completely stabilized--except for one small washout on the steepest hill. Cover and growth excellent.
(15) Whittlesey Watershed (1958-76) (a) Whittlesey Creek Channel (1958-76). This site is located at the mouth of the Whittlesey about 1/2 mile from Lake Superior beginning at the bridge on Highway 13 three miles west of Ashland. In 1949 the U.S. Corps of Army Engineers established a new channel to eliminate the frequent flood road and bridge damage occurring up to 1949. The new channel	Dredge original channel and revert flow to it. Minimum maintenance dredging (cost about $500) was applied in 1960.	1960: Redredging very effective. 1963: The 1958 original channel diversion and the 1960 maintenance dredging remain very effective with no further evidence of sedimentation. 1976: The drainage is effective and there is little evidence of any sedimentation since 1963.

Sites and Characteristics	Objectives and Experimental Work Performed and Date	Results and Recommendations
filled within a few years and flooding and serious erosion damage continued. In 1958 the RCIC diverted the channel to its normal course for a cost of about $1,500.		
(16) Galligan Bros. on Whittlesey (1958) The stream bank has several raw, steep red-clay banks with sand lenses.	Determine whether stream bank erosion can be controlled. Treatments included: several methods of mulching and mulch materials; toe stabilization with cement bagging and willow planting (see report in text) and bulldozing new channels and banks. The owner of one bank with town assistance, bulldozed and graded upper part of bank (removed overhang) and installed diversion. 400 #/A 10-10-10, straw and asphalt. Some florocaps with hydroseeder included crownvetch, and some woody species.	In 1958 when most of the mulching work was done, heavy rains washed off the mulch and seeding. While the cement bagging retarded erosion, it was washed out in two years. Some of the willows remain, but without other toe stabilization work, are only very limited in erosion control. Bulldozing of a new channel and bank in 1962 has been effective but more maintenance work is needed. 7-20-1976 This big bank is 90% protected with a good cover. About 10% still subject to erosion. The area that has not healed is immediately below an overhang. Birdsfoot trefoil found throughout long slope but mainly in upper half. In lower portion of slope, crownvetch is giving excellent cover and protection. Some woody invasion very evident with blackberry, poplar, aspen, etc. On the smaller sites with shorter slopes located approximately 100 yards downstream, where only natural revegetation has taken place, the bank is only 40 to 45% covered after this 18-year period. This points out the value of reseeding and mulching since during the insuing year many tons of sediments needlessly washed away.

Sites and Characteristics	Objectives and Experimental Work Performed and Date	Results and Recommendations
(10) Brule River Stream Bank - Gabions(1964) Located about one-fourth mile south of Brule, WI. Steep red clay banks. These are mostly exposed to the south and on a sharp turn of the Brule River.	Stream bank control using rock filled wire baskets or Gabions. Some willows were planted on the steep slopes. Willows had been healed in for sometime prior to planting. Work performed by DNR crew. Gabions were constructed of heavy, zinc-coated chicken wire. (Not standard Gabion basket).	1966-73 Gabions have done an excellent job of toe stabilization. Willows never did grow well. There was fair initial survival but gradually they disappeared. 7-20-1976 Many Gabions have opened at the bottom and rocks are coming out of the basket. The rocks are still pretty much in place and the wire is intact on the top. Clay moving down the slope has largely covered the Gabion creating an added measure of stability. It is doubtful that the rocks can withstand much flooding or iceflow. No willows found. Banks have considerably woody invasion. Some people traffic. Disappointed that the Gabions did not last longer (note construction material).
Miscellaneous		
(5) Glob Seeding of Woody Species At Highway 13 (Sand River) site.	To directly seed woody species including some shrubs and tree species using a hydroseeder. Tree seed is mixed in a rather heavy slurry and applied in "globs," May 19, 1964.	1964: Torrential rains immediately after the "glob" seeding washed most of the mulch and undoubtedly most of the seed away. On June 9, 1964 a few trees and shrubs were germinating. This turned out to be a very dry year. 7-20-1976 Some shrubs and small trees are growing on most of the areas "glob" seeded. After 12 years these woody plants growing undoubtedly have come from nearby seed sources. "Glob" seeding of woody species for all apparent purposes has been unsuccessful in the red clay area.

PHASE I

FIVE COUNTY ROADSIDE/STREAMBANK RED CLAY EROSION SURVEY: WISCONSIN/MINNESOTA

by

D. R. Bray, P. L. Webster, D. J. Call and A. B. Dickas*

In a contract dated 4 October 1977, a preliminary investigation was undertaken to establish the known extent of Pleistocene red clay erosion along the transportation network and major stream banks of Douglas, Ashland, Bayfield and Iron Counties, Wisconsin and Carlton County, Minnesota. This contract was drawn up between the Center for Lake Superior Environmental Studies of the University of Wisconsin-Superior and the United States Environmental Protection Agency (acting through their Grant Number G-005140) with two (2) specific questions in mind, as follows:

1. Within the five (5) county subject area what is the extent of Pleistocene aged red clay sedimentation?
2. Of this sedimentation extent, how much has been analyzed as to the extent and habit of roadside and trunk streambank erosion?

Preliminary discussion indicated the best approach to the solution to these questions was through the five (5) stages listed below (as outlined in the contract).

1. Establish a five (5) county base map of scale allowing ease of determination of geographic area and length.
2. Establish as an overlay the extent (outline) of known red clay sedimentation.
3. Search regional and state records and collect copies of all that pertains to past surveys of subject area roadside and streambank erosion.
4. Compile such records into an uniform format.
5. Establish as an overlay, and in cartographic code, the pertinent and relevant information obtained in stage 4.

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*Center for Lake Superior Environmental Studies, University of Wisconsin-Superior.

These tasks were accomplished throughout the period October 1977 - April 1978 by the signatories of this report. Details and final results of each state consititue the remaining portions of this report.

ESTABLISHMENT OF FIVE COUNTY BASE MAPS

From a list of individuals compiled in association with Mr. Steve Andrews, Project Director of EPA grant number G-005140, maps were sought which displayed the required road network, political boundaries and stream systems. After comparison of various maps (State Highway, United States Geological Survey, Soil Conservation Center, etc.), two were chosen for establishment of a master base set.

The Wisconsin base was obtained from Mr. Thomas Weix, Area Resource Conservationist with the Pri-Ru-Ta Resource Conservation and Development (RC&D) project office, Spooner, Wisconsin. This map contained all four Wisconsin subject counties drawn to a scale of 1/253,440 (1" = 4 miles). A similar map for Carlton County, Minnesota, drawn to the scale of 1/220,400 (1"= 3.5 miles) was obtained from Mr. Donald Benrud, District Conservationist with the Soil Conservation Service, Barnum, Minnesota.

Because of scale differential, and for ease of handling, a common base was established with a scale of 1" = 1.33 mile. For clarity of data presentation it was decided to present each county as a separate base map, with Bayfield County subdivided as a result of overall county dimensions. Thus, as a final product six (6) county bases, to an uniform scale, were drafted.

Scale uniformity was established by use of a Model 55 Map-O-Graph, with technical assistance from Professor Adolf Kryger of the University of Wisconsin-Superior Geosciences Department. The Map-O-Graph projection was initially traced in pencil onto Albany tracing paper as a series of draft maps. From this pencil draft a final copy series, employing India ink and Chartpak transfer lettering, was constructed. These final maps were drawn in two (2) colors: black for lettering, political units and transportation network, and blue for trunk and tributary drainage courses.

ESTABLISHMENT OF KNOWN RED CLAY SEDIMENTATION OVERLAY

Because of financial difficulties associated with multiple reproduction of this proposed overlay, it was commonly agreed by both contractee and contractor that this boundary should be added to the master set of six (6) maps. Thus this boundary, in red, constituted the third (3rd) color to be employed on the master maps.

The Wisconsin extent of known red clay sedimentation was transferred off a Pri-Ru-Ta soil map titled "Land Resource Areas Map," dated 10 October 1968. Comparable Minnesota information was supplied by Mr. Donald Benrud from Soil Conservation Service records.

Transferral to the master maps was again accomplished by Map-O-Graph projection.

SEARCH FOR RECORDS OF PAST SURVEYS OF SUBJECT ROADSIDE AND STREAMBANK RED CLAY EROSION

Many individuals and organizations were contacted in person or by telephone survey so as to uncover this information. The results of these surveys are given in outline form for ease of presentation. Most, if not all, shoreline has been identified as erosion, however, specific sites have not been identified.

Wisconsin Sources

--Dr. Meredith Ostrom (State Geologist) and Mr. Roger Springman of the Wisconsin Natural History and Geological Survey, Madison, Wisconsin. This source could offer no direct help or data other than a contract which had been let to Dr. Joseph Mengel of Superior, Wisconsin, to analyze overall sediment load of certain northern Wisconsin streams. While this study is still underway, it will not directly relate to locations or extent of streambank erosion.

--Mr. Richard Livingston of the Northwest Wisconsin Planning Commission office in Spooner, Wisconsin. While this commission has planning studies underway for future soil erosion control, their files did not contain any present data on the subject.

--Mr. William Rose of the United States Geological Survey regional office in Madison, Wisconsin. While this source had much information on northern Wisconsin stream discharge, sediment bed load and regional geology, they possessed no specific red clay erosion information.

--Mr. John Streich, Conservationist with the Douglas County Soil Conservation District in Superior. This service was able to contribute much information and ultimately was responsible for supplying the majority of subject matter for Douglas County.

--Mr. Thomas Weix, Area Resource Conservationist with Pri-Ru-Ta RC&D project office, Spooner. Except for supplying the original map employed in drafting the Wisconsin master base maps, no additional data was available from this source.

--Mr. Gregory Sevener of the State of Wisconsin Department of Natural Resources office in Spooner, Wisconsin. No red clay soil erosion information was available.

--Mr. Emil Meitzner, Materials Engineer with the Superior Office of the Wisconsin Department of Transportation. This office supplied maps and descriptions of numerous erosion sites along state and county roads in Douglas, Bayfield and Ashland Counties. Only a minority of these sites had a description of erosion problems and recommendations; the remaining listed only geographic location and approximate length with no additional data.

--Mr. Clarence Austin, District Manager of the Soil Conservation Service for Ashland, Bayfield and Iron Counties. This source, coupled with that information obtained from Mr. John Streich, supplied the majority of the Wisconsin data obtained in this report.

--Mr. Dennis Van Hoff of the Ashland Office, Coastal Zone Management program. Here reference was given to the Northwest Wisconsin Planning Commission office.

Minnesota Source

--Mr. Donald Benrud, District Conservationist, Soil Conservation Service, Barnum, Minnesota. From this excellent source it was learned that the roadways of Carlton County had been totally surveyed for soil erosion characteristics and that few of the rivers within the red clay belt had been similarly analyzed. This resulted in the sole source of Minnesota information.

COMPILATION OF SOIL EROSION RECORDS INTO AN UNIFORM FORMAT

All such records have been reproduced and are presented within this report. In many cases the information had to be typed as the originals were in the form of field notes. Maps and/or copies of aerial photographs are also included for complete reference.

The formats have been minimized as much as possible. In those very few cases where it was deemed desirable to continue the format as presented, so as to not lose any information in translation, the original style of presentation was maintained.

ESTABLISHMENT AS AN OVERLAY SYSTEM, IN CARTOGRAPHIC CODE, THE PERTINENT INFORMATION OBTAINED IN STAGE THREE

During this final stage the information that was gathered and compiled during stages three (3) and four (4) was reconstituted onto a MYLAR plastic sheeting overlay for each of the master set of six (6) base maps. Each overlay was registered to the master set. An acceptable cartographic code was determined as a result of several meetings between the contractor and contractee, as follows:

--solid orange line superimposed over the transportation network will indicate where red clay erosion surveys have already been accomplished

--solid orange data adjacent to the roadways will indicate a construction site (potential--sites may or may not have had construction done: reference back to technical appendix for further reference to actual work sites) such as seeding, mulching cribbing or soil bank grading

This singular color was chosen due to expenses of multi-color printing of the MYLAR overlays.

In addition to the above work, conducted according to specifications of the contract, several additional services were rendered by the Center for Lake Superior Environmental Studies. These involve the following:

--production of twenty-five (25) black line ammonia copies of each of the six (6) master maps with the red clay sedimentation boundary outlined in red; total copies equal one hundred and fifty (150)

--printing of twenty-five (25) single color copies each of the MYLAR overlay for each of the six (6) master maps by Weber Printing Company of Park Falls, Wisconsin; total copies equal one hundred and fifty (150)

PHASE II

FIELD ANALYSIS OF RED CLAY STREAMBANK AND HIGHWAY EROSION

by

D. R. Bray, P. L. Webster and A. B. Dickas*

In a contract dated 4 October 1977, a preliminary investigation was undertaken to establish the known extent of Pleistocene red clay erosion along the transportation network and major streambanks of Douglas, Ashland, Bayfield and Iron Counties, Wisconsin and Carlton County, Minnesota. This contract was drawn up between the Center for Lake Superior Environmental Studies of the University of Wisconsin-Superior and the United States Environmental Protection Agency (acting through their Grant Number G-005140) with two (2) specific questions in mind, as follows:

1. Within the five (5) county subject area what is the extent of Pleistocene aged red clay sedimentation?
2. Of this sedimentation extent, how much has been analyzed as to the extent and habit of roadside and trunk streambank erosion?

The solution of these questions was accomplished in a five (5) stage process, conducted during the period October 1977 into April 1978:

1. Drafting of five (5) county base maps of scale allowing ease of determination of geographic area and length.
2. Drafting of an overlay system displaying areas of recorded red clay roadside/streambank erosion.
3. Superimposition of known extent of red clay sedimentation on base maps.
4. Search of regional and state records and collection of all information that pertains to past surveys of subject erosion.
5. Compilation of such records and maps into a uniform format report.

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*Center for Lake Superior Environmental Studies, University of Wisconsin-Superior.

In late April of 1978 the above tasks were completed and submitted to Mr. Steve Andrews, Project Director of the Red Clay Erosion Demonstration Project. At that time one final task remained: that of surveying the erosion sites in those areas of the five county subject area that had yet to be analyzed. This report deals with the accomplishments completed under this second phase.

After several meetings with Red Clay Project personnel it was agreed that a complete survey, including all stream trunk streams and first order tributaries, and remaining roadside analysis, could not be accomplished in the designated period June through August 1978. Rather four (4) target areas were chosen for additional erosion data collection. These areas were:

1. All remaining stretches of roadside erosion.
2. A sector of a red clay basin that has been subjected principally to recreation usage.
3. A sector of a red clay basin that has been utilized principally for agricultural purposes.
4. A sector of a red clay basin that has been maintained basically in a virgin state.

SPECIFIC TARGET AREAS

From Phase I review it was learned that the majority of the roadsides within the five (5) county red clay zone had been erosion surveyed to date. The two (2) remaining sectors completed during Phase II were:

1. All roadsides within Ashland County within the townships of Gingles, Sanborn, and White River, plus portions of Marengo, Ashland and Morse Townships.
2. Roadsides within the following townships of Douglas County: Parkland, Northern Oakland, Amnicon, Northwest Hawthorne, Cloverland, Northern Brule and Northern Maple.

This analysis entailed driving all state, county and township roads in the above mentioned sectors to locate and catalogue all roadside erosion sites. Locations were plotted on a cartographic overlay to be employed in conjunction with the maps completed during Phase I. Each written description contains dimensions in feet (length, width and height), type of erosion and volume of erosion. The format of this data presentation conforms to that used in the Carlton County section of the Phase I final report for ease of comparison.

As previously mentioned, sections of three (3) red clay drainage basins were chosen for purposes of comparing red clay erosion along trunk stream courses being utilized for differing purposes. After field analysis, attempts were made to compare and contrast erosion data so as to determine human impact versus natural erosion within these differing basins. The Bois Brule of Douglas County and the White River of Bayfield/Ashland County were canoed, while the North Fish of Bayfield was analyzed on foot. Specific tasks included location of erosion sites on a topographic map base, determination of dimensions (length, width and height) of erosion site in feet, type of erosion (slide or washout), probable cause and approximate age. As in the roadside analysis, these locations are presented in outline description and are plotted on an overlay to be used with the maps constructed during Phase I. Again, the format previously employed within Carlton County was utilized for ease of comparison.

In both roadside and streambank analysis black and white photographs were occasionally taken of unusual slides so as to make the written description more meaningful to the reader.

A description of the specific stretch or trunk stream within each basin is as follows:

1. Bois Brule River: that approximate sixteen (16) mile length of thalweg lying between the intersection of Highway FF north to entry into Lake Superior. This river was chosen because it is utilized basically as a recreational water course: fishing, canoeing and kayaking.

2. North Fish River: that approximate twenty (20) mile length of thalweg lying between the upper crossing of Highway 2 (Section 29, T47N, R6W Bayfield County) and the crossing of Highway 2 near the University of Wisconsin Experimental Station (Section 2, T47N, R5W Bayfield County). This site was chosen as one heavily influenced by agricultural utilization.

3. White River: that approximate fifteen (15) mile length of thalweg from near intersection of Highway 63 with County Road E (Section 1, T45N, R6W Bayfield County) northeast to the White River Flowage Dam (Section 6, T46N, R4W Ashland County). This stretch of river was chosen as an area representative of a relatively virgin sub-course, minimally impacted by the activities of man.

GENERAL REPORT OF ACTIVITIES

The portion of this survey concerning roadside erosion was completed during the period from June 5 to July 3, 1978. Before beginning the actual survey a meeting was held with Donald Benrud and his staff at Barnum, Minnesota in order to determine exactly how the survey of Carlton County was originally conducted, i.e. the survey after which Phase II work would be patterned. It was found that the original surveys were done quite early in the spring of the year when vegetation cover was minimal. Nevertheless, it was agreed that an adequate and comparative job during the month of June could be conducted. Mr. Benrud additionally supplied information relating to field methodology and level of data accuracy.

All above mentioned roads were driven by project associates Paul L. Webster and David R. Bray, one driving, and one keeping notes and recording data. Each site was plotted on a standard township map and later transferred to a plastic overlay created in Phase I of this project. Each map site was numbered and a corresponding description was recorded. This description included dimensions of the site in feet (length, width, depth) from which volume was calculated. Type of erosion was recorded as either sliding or washing, and classified as either disturbance or inadequate design. Location was noted as ditch bottom, inslope, or backslope or some combination of the three, and an attempt was made to date the site as either under or over three years of age. Additional notes were added where necessary.

The accuracy of measurement or roadside erosion was made to the nearest foot, though it was found that in longer sites accurate measurement of depth and width was highly subjective because each varied greatly along the length of a chosen site. In order to arrive at an acceptable estimate of volume, it was necessary for the project personnel to average depth and width along any individual erosion site length.

That portion of this survey concerning streambank erosion was completed in the period from July 6 to August 1, 1978.

The streambank erosion survey entailed many different problems even though the same general type of data determined as a result of the roadside surveys was sought. A similar data format was employed for the roadside survey except that the section on "Location" and that on "Cause" was deleted. Instead of recording site locations on township maps, topographic maps were employed which intended to portray better detail concerning the rivers flow plus a better overall indication of bank elevation, as expressed by contour analysis.

Because of time limitations and difficulties of directly measuring each site, it was decided to estimate length as well as width and depth. The largest problem encountered with estimating the width and depth of sites was related to the fact that so much material had slid into the river proper and had thus been completely washed away that it became a matter of attempting to reconstruct approximately what each site had looked like prior to the slide and then estimating the differences. Along much of the White River and North Fish Creek every meander along the river contained a major slide. For the most part the slides were not active at the time of site visit, although some heavy rains were encountered during the field season.

In reviewing the relationship of erosion to use activity in the differing river basins studied, it was found that despite the differing natures of the three rivers (natural, agricultural and recreational) the major cause of erosion in all three was basically natural (i.e. direct erosion by differential stream discharge and undercutting and resulting slumping of streambanks) and thus would be virtually uncontrollable. In only a few sites was erosion seen that could directly be related to agricultural use and here the direct cause was that of migrating livestock. Man-caused erosion was evidenced only along the Bois Brule River at recreational canoe entry and exit sites near the highway FF bridge and along highway 13, and even here damage was categorized as minor.

The remaining portions of this report contain details regarding each specific and analyzed erosion site.

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(Please read Instructions on the reverse before completing)

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15. SUPPLEMENTARY NOTES

Section 108(a) Program Coordinator-Ralph G. Christensen
U.S. EPA Project Officer- Carl D. Wilson

16. ABSTRACT

This project was in support of the Federal Water Pollution Control Act(PL 92-500). The objectives are to demonstrate economically feasible methods of improving water quality, to assess the capabilities of existing institutions to cooperatively implement a pollution control program and to provide data recommendations that could be used in future programs. The monitoring of water quality and climatic conditions were carried out in all geographic areas where research and field demonstration activities were performed. This document is the final report of the Red Clay Project.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Sediment Erosion Water Quality Institutional Socio-economic Nutrients Land treatment		

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